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YAWSONDE TESTS OF 2.75-INCH Mk66 MOD 1 ROCKET

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August 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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The Mk66 Mod 1 is a 2.75-inch rocket which uses three wrap-around fins for flight stabilization and roll control. Performance requirements made it necessary to closely control the spin history of the rocket over its trajectory so as to avoid a resonance region. The BRL performed a small yawsonde test program to measure the roll history and yaw behavior for selected fin configurations. This program was done at the request of the Naval Ordnance Station, Indianhead, Maryland.

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20. ABSTRACT (continued)

Four 2.75-inch rockets were instrumented with yawsondes and fired at the Transonic Range Facility of the BRL at Aberdeen Proving Ground. Flight data showed that none of the fin designs produced pitch/roll lock-in. Moreover, the fin designs were able to produce close to the desired roll histories. Maximum spin was less than 35 rps at rocket burn-out (about 1 second into the flight). Spin reversal occurred at about 1.5 seconds. A spin minimum existed at about six seconds. Near impact, both fin designs achieved steady state spin of 17 rps. The yawsonde data show a tendency to yaw at spin reversal and near the minimum spin condition. A late flight instability was also observed on two rockets.

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I. INTRODUCTION

The 2.75-inch Mk66 Mod 0 rocket was developed by the U.S. Navy in the early 1970's. A design requirement during development was the capability of fire from either an airplane or a helicopter. Improvements in rocket nozzle and propellant produced increased launch velocities and spin rates. The Mk66 Mod 0 used three wrap-around fins. The Naval Ordnance Station (NOS), Indianhead, Maryland has been working on a limited redesign of the system during the last three years[1] to produce a close control of the rocket roll rate history. One modification produced by the NOS was a fluting of the exhaust nozzle to obtain a spin of 10 rps at launch. This was to minimize the effects of thrust misalignment, tip-off, and rotor downwash[2].

There exist several limitations on the roll history of the rocket. In order to arm the weapon, a sizeable initial spin is required. This spin, however, must remain below 60 rps or the arming mechanism will not function properly. For the warhead to function properly, the final spin must be within a band of ± 25 rps. The rocket must not dwell near the pitch frequency of the system, 8 Hz at Mach 2 and 4 Hz subsonically, so as to avoid the possibility of pitch/roll lock-in. This final requirement was difficult to meet with the wrap-around fin design of the Mk66 Mod 1 rocket with fluted nozzle.

Wrap-around fins are known to produce roll reversal as the projectile slows down to subsonic speeds. Thus, at some point in flight, the Mk66 Mod 1 roll rate would be close to the pitch frequency. The original wrap-around fin configuration produces a steady state subsonic roll rate of about -5 rps. The NOS has been attempting to tailor the subsonic roll rate of the rocket by modifying the leading and trailing edges of the fins.

During 1979, the NOS had tested four different modified fin configurations at White Sands Missile Range, New Mexico, and at the Naval Surface Weapons Center, Dahlgren, Virginia. From the results of these tests[1], a fin configuration (designated 1-1B2) was selected for further development. This design had a symmetric leading edge of double 10° bevels and a 10° bevel cutout (15mm long) on the concave side of the trailing edge. Two free flight tests of this design indicated satisfactory performance and a wind tunnel test program[3] was planned to study the aerodynamic properties of the

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1. *D.M. Bergbauer, J.H. Ferguson, R.W. Bergman, and R. Bentley, "Spin Profile Tailoring for the Improved 2.75-Inch Rocket", AIAA Preprint No. 80-1575-CP, Atmospheric Flight Mechanics Conference, August 1980.*

2. *D.M. Bergbauer, J.H. Ferguson, R.W. Bergman, and R. Bentley, "Evaluation of Ground-Launch Firings for the Improved 2.75-Inch Rocket", AIAA Paper No. 79-1297, AIAA/SAE/ASME 15th Joint Propulsion Conference, June 1979.*

3. *Request from Commander, Naval Ordnance Station to Director, NASA Ames Research Center, "Wind Tunnel Test Program for 2.75-Inch Rocket", dated 7 December 1979.*

configuration. In order to prepare for the wind tunnel tests, NOS requested that BRL instrument four Mk66 Mod 1-1B2 rockets for spin. The BRL added the ability to measure yaw and this report presents preliminary spin and yaw data obtained for two fin configurations.

II. TEST SET-UP AND INSTRUMENTATION

The instrumented test program of the Mk66 Mod 1 rocket was fired at the Transonic Range Facility of the BRL at Aberdeen Proving Ground, Maryland. Since this rocket is a new design for which BRL had no suitable launch tube, a special launch tube was provided by Messrs. Bergbauer and Ferguson of the NOS. A rocket-launcher mount was borrowed from the Materiel Testing Directorate, also located at Aberdeen Proving Ground. Figure 1 is a photograph of the launcher and mount. The yawsonde-instrumented rocket prior to launch is shown in Figure 2.

Two 16mm framing cameras were located about 10 and 15 metres from the launcher to monitor metal parts integrity and wrap-around fin opening. No velocity measurements were attempted. The yawsonde telemetry was monitored by a portable ground receiving station located 1,000 metres behind the launch site.

The rocket spin history and dynamic behavior were obtained using a modified yawsonde shown in Figure 3. The detection circuitry and electronic components of this unit were very similar to those of a standard yawsonde assembly[4,5]. The major modification consisted of the use of a different power supply. The standard power supply for the BRL yawsonde is a PS119 acid-plate battery. The acid is contained in a glass vial which must break on launch at a minimum acceleration of about 1,000 g. Moreover, the acid is distributed to the plates by centrifugal force and the battery requires a minimum spin rate of 40-50 rps for proper operation. Since neither condition could be met by the Mk66 Mod 1 rocket, the PS119 battery was replaced by a rechargeable Nickel-Cadmium power supply. To preclude power drainage, a manual turn-on switch was used. Figure 4 shows the modified base cap with turn-on switch. The Mk66 Mod 1 rocket with yawsonde instrumentation is shown in Figure 5.

Four yawsonde-instrumented test models with the same mass properties as a rocket with live warhead were prepared by NOS. The measured physical characteristics of these models are listed in Table 1. The leading edges of the fins of rockets A1 and A2 were different from those of rockets B1 and B2.

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4. *W.H. Mermagen and W.H. Clay, "The Design of a Second Generation Yawsonde", Ballistic Research Laboratories Memorandum Report No. 2368, April 1974. AD 780064.*

5. *W.H. Mermagen, "Measurements of Dynamical Behavior of Projectiles over Long Flight Paths", Journal of Spacecraft and Rockets, Vol. 8, No. 4, April 1971, pp. 380-385.*

The launcher was emplaced at the Transonic Range Facility of the BRL (76.11 deg longitude and 39.54 deg latitute) along an azimuth of approximately 190 deg from true North. During the month of November, when the tests were fired, it was possible to fire yawsondes either in the morning (prior to 10:00 AM EST) or in the afternoon (after 3:00 PM EST). Table 2 presents the firing data. Rocket A1 was fired despite the fact that yawsonde 1730 could not be received on the ground when powered by internal battery. When the same condition occurred with yawsonde 1729, the unit was returned to the electronics laboratory and checked. Tests indicated that the power supply was discharged. The unit was charged overnight and firing was completed on 7 November 1980. The temperature at the APG Meteorological Station was 11^{o}C (52^{o}F) on 6 November and 17^{o}C (63^{o}F) on 7 November at the time of the test firings.

III. DATA REDUCTION AND ANALYSIS

The yawsonde data from the test firings were easily processed for roll rate but difficulties were encountered in processing and analyzing for yaw. In order to understand the roll and yaw analysis, a brief description of the yawsonde and the processing technique is presented here.

The yawsonde is an electro-optical device comprising a pair of photovoltaic sensors mounted behind slits on the exterior walls of the sonde. The sensors respond to light by producing voltage. The slits are skewed with respect to the roll axis of the vehicle. As the projectile rotates about its axis, each slit (sensor) in turn is illuminated by the sun and corresponding voltage pulses are produced. The sensor outputs are fed into an impedance matching amplifier and the polarity of one sensor is inverted with respect to the other. The amplifier drives a voltage-controlled-oscillator (VCO) which in turn modulates a radio-frequency-oscillator (RFO). The complex radio-frequency signal is transmitted to ground receiving stations and the video portion is recorded on magnetic tape.

During tape playback, the video signal is discriminated and the pulse train is fed into an electronic device which measures the time intervals between pulses and stores these intervals in computer memory. Figures 6A - 6C show examples of the pulse train from the sensors aboard one of the rockets while in flight. The time indicated on each Figure is with respect to a manual time-zero. Figure 6A shows pulses from a part of the flight immediately after launch. Figure 6B shows a segment of the pulse train in the region where the rocket changes spin direction due to the aerodynamic action of the wrap-around fins. Figure 6C shows the pulse train during the reverse-spin plateau region. The frequency of occurrence of the pulses is seen to be different in all three figures, an indication of the changing roll rate of the vehicle. Figure 6B shows the change of roll direction. A positive pulse is missing at 2.95 seconds after manual time-zero. The pulse is not really missing; the sensor did not see the sun at that time because the roll direction reversed before the sensor could be illuminated.

Another feature of the pulse train for these rocket rounds is that the pulse widths change during the changing roll portions of the flight.

The usual method used at BRL for reducing the pulse data is to consider the time intervals between leading edges of pulses. The calibrations, however, are taken at roll orientations which correspond to pulse peaks. Since the pulse widths were variable, the processing technique was modified so that time intervals were measured between pulse half-widths. The reciprocal of the time interval between successive positive or successive negative pulses is the average roll rate of the vehicle in rps. More accurately, this reciprocal of time interval is the Eulerian roll rate, i.e., the time derivative of the Eulerian roll angle. The phase relationship between positive and negative pulses is a measure of the solar aspect angle, i.e., the angle between the axis of the vehicle and a vector directed toward the sun. For small yaw, say less than ten degrees peak-to-peak, the phase changes are small and cannot be seen in traces such as shown in Figures 6A - 6C. These phase differences, however, are quite obvious to an electronic time-interval measurement system and can be related to solar aspect angle values through calibration.

The usual method for treating the yawsonde pulses is to form time intervals between either the positive or the negative pulses, form the reciprocals, and plot the result against time for a measure of the Eulerian roll rate, called PHI-DOT. For these 2.75-inch rocket firings, both the positive and negative pulses were used to obtain PHI-DOT. Solar aspect angle information is obtained by forming the ratio of the difference between a plus-minus pulse pair and a plus-plus pulse pair. The ratio is then compared to a calibration curve[6] of such ratios versus aspect angle. Additional ratios of minus-plus to minus-minus pulse intervals were formed and used to provide more data points. These additional data points are needed in regions where the solar aspect angle can change during a single roll period, particularly for the case where the pitch and roll rates are of the same order of magnitude.

IV. RESULTS

The four instrumented rockets were identified as Rocket Number A1 (Yawsonde 1730), Rocket Number A2 (Yawsonde 1732), Rocket Number B1 (Yawsonde 1731), and Rocket Number B2 (Yawsonde 1729). All four rockets employed wrap-around fins. Rockets A1 and A2 had the same leading edge chamfer on the fins while rockets B1 and B2 had different leading edge chamfers from the A rockets. Rockets A1, A2, and B1 were fired on the afternoon of 6 November 1980 while number B2 was fired on 7 November 1980. Rocket A1 did not transmit due to battery failure. The framing cameras used to monitor the metal parts integrity and fin openings showed successful launches and openings on all flights. Figure 7 is a photograph of Rocket Number B1 in flight and is typical of all four rockets fired.

The spin data from Rocket A2 are shown in Figure 8. Plotted are the Eulerian roll rates PHI-DOT as a function of time of flight. The time of

6. *W.H. Clay, "A Precision Yawsonde Calibration Technique", Ballistic Research Laboratories Memorandum Report No. 2263, January 1973. AD 758158.*

flight was adjusted from the raw data so that peak positive roll rate (rocket burnout) occurs at 1.0 second after launch. Figures 9 and 10 show the roll histories for rockets B1 and B2. Except for small differences in amplitudes, all three rounds had similar roll behavior. The curves for rockets B1 and B2 are almost identical and differ from the rocket A2 behavior only in the amplitude of the roll rate at two seconds. Positive roll rate or PHI-DOT for these results is in the direction of a right-hand screw advancing in the direction of flight.

The yaw data from the rockets are shown in Figures 11 - 13. These results were obtained using standard two-sensor reduction methods. Plotted are the complementary solar aspect angles, SIGMA-N, as functions of time of flight. Time of flight, again, has been normalized to time of rocket burnout at one second. The complementary aspect angle is simply 90° - SIGMA and is used as a convenience. Positive values of SIGMA-N indicate that the sun was forward of the projectile's midplane.

Figures 11 - 13 show different average values of solar aspect angle due to the firings occurring at different times of day and on different days. Figures 14 - 16 show the same data with solar aspect angle for zero yaw plotted as a reference. The aspect angle for zero yaw is usually obtained from measured values of the projectile velocity vector and the location of the sun. Since no tracking point-position radar was used in these tests, the velocity vector data were computed from a modified point mass trajectory code. The average aspect angle for all three rockets agrees well with the computed zero-yaw aspect angle data at launch. Later in the flight, however, the average aspect angle departs from the computed zero yaw. The curvature in the SIGMA-N plots is due to trajectory curvature. On all three rockets, the yawsonde plots show yawing motion near roll reversal and near six seconds into the flight. Two rockets (A2 and B1) also showed an undamped slow mode at the termination of the flight.

V. DISCUSSION

Several features of the roll and yaw data presented here require some discussion. The nature of the trajectory simulation, the roll results and comparisons of spin histories for the two fin designs, spin as a function of Mach number, and the yaw data are considered in detail.

A. Trajectory Simulation

The yawsonde program was performed in preparation for a wind tunnel test program[3] where spin behaviors of various fin designs as a function of Mach number are important. Since independent trajectory data were not obtained, a computer simulation was used to determine Mach number as a function of flight time. The computer simulation used a modified trajectory model which did not include the spin variations observed in the real flight. It is not expected that this lack will appreciably affect the Mach number history. The computed trajectory parameters* of the

*The computer trajectory simulation was provided by Mr. Chase of BRL's Firing Tables Branch.

rocket flight are listed in Table 3. Two different Mach number values are shown because of the temperature differences between the two firing days. A plot of Mach number versus flight time is given in Figure 17. Both Figure 17 and Table 3 show that the effect of temperature variation between the two test days results in a difference of at most 0.02 in computed Mach number at rocket burnout. Therefore, an average Mach number will be used during the remainder of the discussion.

B. Spin Data

The spin data from rockets B1 and B2 are almost identical and indicate consistent performance for the fin design for those two rockets. The spin data from rocket A2 is slightly different, however, due to a difference in leading edge chamfer. The fin design used on rocket A2 produced a higher reverse spin soon after crossover as compared to rockets B1 and B2. The minimum value of reverse spin (at about 6 seconds) for rocket A2 is lower (-1.5 rps) than that for rockets B1 and B2 (about -2.5 rps). After nine seconds of flight, the behaviors of all three rockets are essentially the same. Near impact, the steady state spin is about -17 rps for all rounds. Tables 4 - 6 list the measured spins over the entire flights. Figure 18 is a comparison of the spin histories of rockets A2 and B2 and also shows the computed Mach number history.

C. Yaw Data

The yaw histories shown in Figures 11 - 13 show similar behavior for rockets B1 and B2 while rocket A2 seems to behave somewhat differently during the first half of the flight. All three rockets showed a tendency to undamp at roll reversal and near the negative spin minimum (about 6 seconds). The solar aspect angle amplitudes in the regions from 1 - 2 seconds and from 4 - 7 seconds are not accurate. To see why this is so, consider Figures 19 - 21 in which the solar aspect angle and the spin are plotted for each rocket. In the first region, between 1 and 2 seconds, the roll reverses suddenly. The yawsonde processing algorithm is not accurate when both roll and yaw are changing rapidly during a roll period. In the region from 4 to 7 seconds, the roll rate is less than 12 rps. The pitch frequency is about the same order of magnitude, close to spin-yaw resonance. The yawsonde does not accurately produce yaw information unless the spin rate is about an order of magnitude greater than the pitch rate. Nevertheless, the indication is that the rockets undergo some yawing motion during this passage through resonance. The solar aspect angle measurements taken during the portions of the flight not affected by roll reversal or by resonance are accurate to within ± 0.2 degree.

Expanded views of the solar aspect angle data are shown in Figures 22 - 24. All three rockets began flight with a very high frequency, low amplitude pitching motion. After roll reversal, the yaw damped to a low amplitude, two-frequency motion which grew gradually in amplitude as the roll rate gradually approached resonance. After passage through resonance, very low amplitude, high frequency, single mode motion dominated the remainder of the flight. Two rockets (A2 and B1) undamped during the terminal phase of the flight, see Figures 11 and 12.

The results of plotting zero yaw computed motion against the solar aspect angle data (Figures 14 - 16) would seem to indicate that the rockets flew at some constant angle of attack during most of the flight. It is probable that some of this effect is due to the simplified aerodynamics used in the computational model. The general conclusion one should draw from the yawsonde data is that the three rockets experienced overall stable flights with minor tendencies to instability at roll reversal, during resonance, and in the terminal phase. The performance through resonance was as hoped for, namely roll-yaw lock-in did not occur.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Messrs. Clay and Davis of the BRL for modification and prompt fabrication of the yawsondes used in this program. The assistance of Messrs. Bergbauer and Ferguson of NOS in providing machine shop time and the rocket launcher was very helpful in the timely performance of the test firings.

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6. W.H. Clay, "A Precision Yawsonde Calibration Technique", Ballistic Research Laboratories Memorandum Report No. 2263, January 1973. AD 758158.

Table 1. Mass Properties of Yawsonde Instrumented Mk66 Mod 1 Rocket

Number	Weight (Kg)	c.g. (m from base)	Moments of Inertia ($Kg\text{-}m^2$) Axial x 10^3	Transverse
A1	10.03	0.813	7.84	2.50
A2	10.07	0.815	7.64	2.52
B1	10.04	0.813	7.64	2.49
B2	10.06	0.813	7.68	2.50

NOTE: Moments of inertia were measured with closed fins.

Table 2. Firing Data for Mk66 Mod 1 Rocket

Date	Time of Launch (EST)	Rocket Number	Yawsonde Number	Remarks
11/6/80	15:40	2011	--	Check Round
	15:50	B1	1731	Good data
	15:57	A1	1730	No transmission
	16:13	A2	1732	Good data
11/7/80	14:54	B2	1729	Good data

NOTE: Rockets were launched at a quadrant elevation of 13.5° (240 ɱ).

Table 3. Computed Trajectory Parameters for 2.75-Inch Mk66 Mod 1 Rocket

Time (sec)	Range (m)	Velocity (m/s)	Mach Number 11/6/80	Mach Number 11/7/80	Elevation (deg)
0.0	0.0	0.0	0.0	0.0	13.5
0.5	70.0	310.0	0.916	0.907	12.4
1.0	326.1	739.8	2.185	2.164	11.8
1.075	382.0	770.2	2.275	2.253	11.8
1.5	784.0	716.0	2.115	2.095	11.4
2.0	1026.9	656.6	1.939	1.921	11.1
2.5	1335.8	604.5	1.786	1.768	10.6
3.0	1621.7	557.1	1.646	1.630	10.1
3.5	1885.1	514.5	1.520	1.505	9.6
4.0	2129.6	476.1	1.406	1.393	9.1
4.5	2356.0	442.1	1.306	1.293	8.4
5.0	2567.5	411.9	1.217	1.205	7.8
5.5	2764.8	385.4	1.138	1.127	7.1
6.0	2950.4	362.0	1.069	1.059	6.4
6.5	3125.1	341.7	1.009	1.000	5.6
7.0	3290.9	324.3	0.958	0.949	4.7
7.5	3448.9	310.3	0.917	0.908	3.8
8.0	3600.9	298.7	0.882	0.874	2.9
8.5	3747.5	288.7	0.853	0.845	2.0
9.0	3889.6	279.7	0.826	0.818	1.0
9.5	4027.2	271.4	0.802	0.794	0.0
10.0	4161.0	263.6	0.779	0.771	-1.1
10.5	4290.9	256.5	0.758	0.750	-2.2
11.0	4417.3	249.8	0.738	0.731	-3.3
11.5	4540.3	243.5	0.719	0.712	-4.4
12.0	4660.2	237.6	0.702	0.695	-5.6
12.5	4776.9	232.2	0.686	0.679	-6.8
13.0	4890.8	227.1	0.671	0.664	-8.0
13.5	5001.8	222.3	0.657	0.650	-9.2
14.0	5110.3	217.9	0.644	0.637	-10.5
14.5	5216.1	213.7	0.631	0.625	-11.7
15.0	5319.5	209.9	0.620	0.614	-13.0
15.5	5420.5	206.3	0.609	0.604	-14.3
16.0	5519.4	202.9	0.599	0.594	-15.7
16.5	5616.0	199.8	0.590	0.584	-17.0
17.0	5710.5	197.0	0.582	0.576	-18.4
17.5	5802.9	194.3	0.574	0.568	-19.7
18.0	5893.5	191.9	0.567	0.561	-21.1
18.5	5982.0	189.6	0.560	0.555	-22.4
19.0	6068.7	187.6	0.554	0.549	-23.8
19.5	6153.6	185.7	0.549	0.543	-25.2
20.0	6236.8	184.0	0.543	0.538	-26.6
20.5	6318.2	182.4	0.539	0.534	-27.9
21.0	6398.0	181.0	0.535	0.529	-29.3
21.45	6468.2	179.8	0.531	0.526	-30.5

TABLE 4. SPIN FOR Mk66 Mod 1 ROCKET NUMBER A 2
YAWSONDE NUMBER 1732.

TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)
0.53	0.60	0.63	9.40	0.68	20.30	0.72	29.90
0.75	31.00	0.78	32.00	0.81	32.50	0.84	32.50
0.87	32.40	0.90	32.30	0.94	32.50	0.97	32.90
1.00	33.60	1.03	34.30	1.05	34.70	1.08	34.70
1.11	34.10	1.14	33.00	1.17	31.40	1.21	29.40
1.24	27.00	1.28	24.00	1.33	19.00	1.44	8.70
1.59	-13.30	1.66	-16.60	1.71	-18.40	1.77	-19.70
1.82	-20.60	1.86	-21.10	1.91	-21.40	1.96	-21.80
2.00	-22.00	2.05	-21.90	2.09	-22.00	2.14	-22.10
2.18	-22.00	2.23	-21.90	2.27	-21.80	2.32	-21.80
2.37	-21.60	2.41	-21.40	2.46	-21.30	2.51	-21.20
2.56	-21.00	2.60	-20.70	2.65	-20.50	2.70	-20.40
2.75	-20.10	2.80	-19.80	2.85	-19.60	2.90	-19.30
2.96	-19.00	3.01	-18.60	3.06	-18.30	3.12	-17.90
3.18	-17.50	3.23	-17.10	3.29	-16.70	3.35	-16.20
3.42	-15.70	3.48	-15.30	3.55	-14.70	3.62	-14.20
3.69	-13.70	3.77	-13.10	3.84	-12.60	3.93	-12.00
4.01	-11.30	4.11	-10.70	4.20	-10.00	4.31	-9.10
4.43	-8.30	4.56	-7.20	4.72	-6.00	4.92	-4.50
5.26	-2.50	5.79	-1.90	6.11	-3.90	6.30	-6.00
6.44	-7.60	6.56	-8.80	6.66	-9.80	6.76	-10.70
6.85	-11.50	6.93	-12.10	7.01	-12.80	7.09	-13.40
7.16	-13.90	7.23	-14.40	7.30	-14.80	7.36	-15.30
7.43	-15.70	7.49	-16.10	7.55	-16.50	7.61	-16.80
7.67	-17.20	7.73	-17.50	7.78	-17.70	7.84	-17.90
7.90	-18.10	7.95	-18.30	8.00	-18.50	8.06	-18.70
8.11	-18.90	8.16	-19.10	8.22	-19.20	8.27	-19.40
8.32	-19.60	8.37	-19.70	8.42	-19.90	8.47	-19.90
8.52	-19.90	8.57	-20.10	8.62	-20.30	8.67	-20.50
8.72	-20.60	8.77	-20.80	8.81	-21.00	8.86	-21.20
8.91	-21.40	8.95	-21.60	9.00	-21.80	9.04	-22.00
9.09	-22.10	9.14	-22.30	9.18	-22.40	9.23	-22.50
9.27	-22.60	9.31	-22.70	9.36	-22.80	9.40	-22.90
9.44	-22.90	9.49	-22.90	9.53	-22.90	9.58	-22.90
9.62	-22.90	9.66	-22.90	9.71	-22.90	9.75	-22.90
9.79	-22.80	9.84	-22.80	9.88	-22.80	9.92	-22.70
9.97	-22.70	10.01	-22.70	10.06	-22.60	10.10	-22.60
10.15	-22.50	10.19	-22.50	10.24	-22.40	10.28	-22.40
10.32	-22.30	10.37	-22.20	10.41	-22.20	10.46	-22.10
10.50	-22.10	10.55	-22.00	10.60	-22.00	10.64	-21.90
10.69	-21.90	10.73	-21.80	10.78	-21.80	10.83	-21.70
10.87	-21.70	10.92	-21.60	10.96	-21.60	11.01	-21.50
11.06	-21.50	11.10	-21.40	11.15	-21.40	11.20	-21.30
11.24	-21.30	11.29	-21.20	11.34	-21.20	11.39	-21.20

TABLE 4. SPIN FOR Mk66 Mod 1 ROCKET NUMBER A 2
YAWSONDE NUMBER 1732 (CONT).

TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)
11.43	-21.10	11.48	-21.10	11.53	-21.00	11.58	-21.00
11.62	-20.90	11.67	-20.90	11.72	-20.90	11.77	-20.80
11.81	-20.80	11.86	-20.80	11.91	-20.70	11.96	-20.70
12.01	-20.60	12.06	-20.60	12.11	-20.60	12.15	-20.50
12.20	-20.50	12.25	-20.50	12.30	-20.40	12.35	-20.40
12.40	-20.40	12.45	-20.30	12.50	-20.30	12.55	-20.30
12.60	-20.20	12.65	-20.20	12.70	-20.20	12.75	-20.10
12.79	-20.10	12.84	-20.10	12.89	-20.00	12.94	-20.00
12.99	-20.00	13.04	-19.90	13.10	-19.90	13.14	-19.90
13.20	-19.80	13.25	-19.80	13.30	-19.80	13.35	-19.70
13.40	-19.70	13.45	-19.70	13.50	-19.70	13.55	-19.60
13.60	-19.60	13.65	-19.60	13.70	-19.50	13.75	-19.50
13.81	-19.50	13.86	-19.40	13.91	-19.40	13.96	-19.40
14.01	-19.30	14.06	-19.30	14.12	-19.30	14.17	-19.30
14.22	-19.20	14.27	-19.20	14.32	-19.20	14.38	-19.10
14.43	-19.10	14.48	-19.10	14.53	-19.00	14.59	-19.00
14.64	-19.00	14.69	-18.90	14.74	-18.90	14.80	-18.90
14.85	-18.90	14.90	-18.80	14.96	-18.80	15.01	-18.80
15.06	-18.70	15.12	-18.70	15.17	-18.70	15.22	-18.60
15.28	-18.60	15.33	-18.60	15.39	-18.50	15.44	-18.50
15.49	-18.50	15.55	-18.50	15.60	-18.40	15.66	-18.40
15.71	-18.40	15.76	-18.40	15.82	-18.30	15.87	-18.30
15.93	-18.30	15.98	-18.30	16.04	-18.20	16.09	-18.20
16.15	-18.20	16.20	-18.20	16.26	-18.10	16.31	-18.10
16.37	-18.10	16.42	-18.00	16.48	-18.00	16.54	-18.00
16.59	-18.00	16.65	-18.00	16.70	-17.90	16.76	-17.90
16.81	-17.90	16.87	-17.80	16.93	-17.80	16.98	-17.80
17.04	-17.80	17.10	-17.70	17.15	-17.70	17.21	-17.70
17.26	-17.60	17.32	-17.60	17.38	-17.60	17.43	-17.60
17.49	-17.50	17.55	-17.50	17.61	-17.50	17.66	-17.50
17.72	-17.50	17.78	-17.40	17.84	-17.40	17.89	-17.40
17.95	-17.30	18.01	-17.30	18.07	-17.30	18.12	-17.30
18.18	-17.30	18.24	-17.20	18.30	-17.20	18.36	-17.10
18.41	-17.10	18.47	-17.10	18.53	-17.10	18.59	-17.10
18.65	-17.10	18.71	-17.00	18.77	-17.00	18.83	-17.00
18.88	-16.90	18.94	-16.90	19.00	-16.90	19.06	-16.90
19.12	-16.90	19.18	-16.90	19.24	-16.80	19.30	-16.80
19.36	-16.80	19.42	-16.70	19.48	-16.70	19.54	-16.70
19.60	-16.70	19.66	-16.70	19.72	-16.70	19.78	-16.60
19.84	-16.60	19.90	-16.50	19.96	-16.50	20.02	-16.50

TABLE 5. SPIN FOR Mk66 Mod 1 ROCKET NUMBER B 1
YAWSONDE NUMBER 1731.

TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)
0.56	16.70	0.64	12.80	0.68	27.90	0.71	29.20
0.74	30.30	0.78	31.20	0.81	31.50	0.84	31.40
0.87	31.40	0.90	31.60	0.93	32.10	0.96	32.80
0.99	33.30	1.02	33.60	1.05	33.60	1.08	33.10
1.12	32.10	1.15	30.70	1.18	28.90	1.22	26.70
1.26	24.20	1.31	19.90	1.44	5.00	1.64	-12.20
1.72	-14.20	1.79	-15.20	1.85	-16.00	1.91	-16.20
1.97	-16.60	2.03	-16.70	2.09	-16.60	2.15	-16.80
2.21	-16.70	2.27	-16.70	2.33	-16.80	2.39	-16.60
2.45	-16.60	2.51	-16.70	2.57	-16.50	2.63	-16.50
2.69	-16.50	2.75	-16.30	2.82	-16.20	2.88	-16.10
2.94	-15.80	3.00	-15.60	3.07	-15.30	3.14	-14.90
3.20	-14.70	3.27	-14.30	3.34	-13.90	3.42	-13.60
3.49	-13.10	3.57	-12.80	3.65	-12.30	3.73	-11.90
3.82	-11.60	3.91	-11.20	4.00	-10.80	4.09	-10.40
4.19	-9.90	4.30	-9.30	4.41	-8.80	4.53	-8.20
4.66	-7.40	4.80	-6.60	4.97	-5.50	5.19	-4.40
5.45	-3.60	5.75	-3.20	6.04	-3.70	6.27	-5.00
6.43	-6.50	6.57	-7.70	6.69	-8.90	6.80	-9.80
6.89	-10.80	6.98	-11.60	7.06	-12.30	7.14	-13.00
7.21	-13.60	7.29	-14.20	7.35	-14.70	7.42	-15.30
7.49	-15.70	7.55	-16.10	7.61	-16.60	7.67	-17.00
7.73	-17.30	7.78	-17.60	7.84	-17.90	7.89	-18.20
7.95	-18.40	8.00	-18.60	8.06	-18.80	8.11	-18.90
8.16	-19.10	8.21	-19.30	8.27	-19.40	8.32	-19.60
8.37	-19.70	8.42	-19.80	8.47	-20.00	8.52	-20.10
8.57	-20.30	8.62	-20.40	8.66	-20.50	8.71	-20.70
8.76	-20.80	8.81	-21.00	8.86	-21.20	8.90	-21.30
8.95	-21.50	9.00	-21.70	9.04	-21.80	9.09	-22.00
9.13	-22.10	9.18	-22.30	9.22	-22.40	9.27	-22.50
9.31	-22.60	9.36	-22.70	9.40	-22.70	9.44	-22.80
9.49	-22.80	9.53	-22.80	9.58	-22.80	9.62	-22.80
9.66	-22.80	9.71	-22.80	9.75	-22.70	9.80	-22.70
9.84	-22.70	9.88	-22.60	9.93	-22.60	9.97	-22.50
10.02	-22.50	10.06	-22.40	10.11	-22.40	10.15	-22.30
10.20	-22.30	10.24	-22.20	10.29	-22.20	10.33	-22.10
10.38	-22.00	10.42	-22.00	10.47	-21.90	10.51	-21.80
10.56	-21.80	10.61	-21.70	10.65	-21.70	10.70	-21.60
10.74	-21.50	10.79	-21.50	10.84	-21.40	10.88	-21.40
10.93	-21.30	10.98	-21.30	11.02	-21.20	11.07	-21.10
11.12	-21.10	11.17	-21.00	11.22	-21.00	11.26	-20.90
11.31	-20.90	11.36	-20.80	11.41	-20.80	11.46	-20.70
11.50	-20.70	11.55	-20.60	11.60	-20.60	11.65	-20.50
11.70	-20.50	11.75	-20.50	11.80	-20.40	11.85	-20.40

TABLE 5. SPIN FOR Mk66 Mod 1 ROCKET NUMBER B 1
YAWSONDE NUMBER 1731 (CONT).

TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)
11.89	-20.30	11.94	-20.30	11.99	-20.20	12.04	-20.20
12.09	-20.20	12.14	-20.10	12.19	-20.10	12.24	-20.00
12.29	-20.00	12.34	-19.90	12.39	-19.90	12.44	-19.90
12.49	-19.80	12.54	-19.80	12.59	-19.70	12.64	-19.70
12.70	-19.60	12.75	-19.60	12.80	-19.60	12.85	-19.60
12.90	-19.50	12.95	-19.50	13.00	-19.50	13.05	-19.40
13.11	-19.40	13.16	-19.30	13.21	-19.30	13.26	-19.30
13.31	-19.30	13.37	-19.20	13.42	-19.20	13.47	-19.10
13.52	-19.10	13.58	-19.10	13.63	-19.00	13.68	-19.00
13.73	-19.00	13.78	-18.90	13.84	-18.90	13.89	-18.80
13.94	-18.80	14.00	-18.80	14.05	-18.80	14.10	-18.70
14.16	-18.70	14.21	-18.70	14.26	-18.60	14.32	-18.60
14.37	-18.60	14.43	-18.50	14.48	-18.50	14.53	-18.50
14.59	-18.50	14.64	-18.40	14.70	-18.40	14.75	-18.30
14.81	-18.30	14.86	-18.30	14.91	-18.30	14.97	-18.30
15.02	-18.20	15.08	-18.20	15.13	-18.20	15.19	-18.10
15.25	-18.10	15.30	-18.10	15.36	-18.00	15.41	-18.00
15.47	-18.00	15.52	-18.00	15.58	-18.00	15.63	-17.90
15.69	-17.90	15.75	-17.80	15.80	-17.80	15.86	-17.80
15.91	-17.80	15.97	-17.80	16.03	-17.70	16.08	-17.70
16.14	-17.60	16.20	-17.60	16.25	-17.60	16.31	-17.60
16.37	-17.50	16.42	-17.50	16.48	-17.50	16.54	-17.50
16.60	-17.40	16.65	-17.40	16.71	-17.40	16.77	-17.30
16.83	-17.30	16.88	-17.30	16.94	-17.30	17.00	-17.20
17.06	-17.20	17.12	-17.20	17.18	-17.10	17.23	-17.10
17.29	-17.10	17.35	-17.10	17.41	-17.10	17.47	-17.00
17.53	-17.00	17.59	-16.90	17.65	-16.90	17.70	-16.90
17.76	-16.90	17.82	-16.90	17.88	-16.90	17.94	-16.80
18.00	-16.70	18.06	-16.70	18.12	-16.70	18.18	-16.70
18.24	-16.70	18.30	-16.70	18.36	-16.70	18.42	-16.60
18.48	-16.50	18.54	-16.50	18.60	-16.50	18.66	-16.40
18.72	-16.50	18.79	-16.50	18.85	-16.50	18.91	-16.40
18.97	-16.30	19.03	-16.30	19.09	-16.20	19.15	-16.20
19.21	-16.30	19.28	-16.30	19.34	-16.20	19.40	-16.20
19.46	-16.10	19.52	-16.00	19.59	-16.00		

TABLE 6. SPIN FOR Mk66 Mod 1 ROCKET NUMBER B 2
YAWSONDE NUMBER 1729.

TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)
0.59	0.60	0.63	22.40	0.67	24.80	0.71	26.70
0.74	28.40	0.78	29.80	0.81	31.30	0.84	32.50
0.87	33.10	0.90	33.20	0.93	33.20	0.96	33.20
0.99	33.50	1.02	34.20	1.05	35.10	1.08	35.80
1.11	36.00	1.13	35.70	1.16	34.90	1.19	33.60
1.22	31.90	1.26	30.10	1.29	28.00	1.33	25.70
1.37	22.30	1.44	14.90	1.68	-9.40	1.77	-12.40
1.84	-14.20	1.91	-15.40	1.97	-15.80	2.04	-16.40
2.10	-16.80	2.16	-16.80	2.21	-17.00	2.27	-17.20
2.33	-17.10	2.39	-17.30	2.45	-17.40	2.51	-17.30
2.56	-17.30	2.62	-17.40	2.68	-17.30	2.74	-17.30
2.79	-17.30	2.85	-17.20	2.91	-17.00	2.97	-16.90
3.03	-16.60	3.09	-16.40	3.15	-16.20	3.21	-16.00
3.28	-15.60	3.34	-15.30	3.41	-14.90	3.48	-14.50
3.55	-14.20	3.62	-13.80	3.69	-13.40	3.77	-13.00
3.85	-12.60	3.93	-12.20	4.01	-11.80	4.10	-11.20
4.19	-10.80	4.29	-10.30	4.38	-9.90	4.49	-9.30
4.60	-8.80	4.72	-8.10	4.85	-7.30	5.00	-6.40
5.18	-5.30	5.40	-4.10	5.69	-3.20	6.05	-2.70
6.35	-3.80	6.56	-5.50	6.72	-7.10	6.85	-8.30
6.96	-9.50	7.06	-10.50	7.15	-11.40	7.23	-12.20
7.31	-12.90	7.39	-13.60	7.46	-14.10	7.53	-14.70
7.59	-15.20	7.66	-15.70	7.72	-16.10	7.78	-16.50
7.84	-16.90	7.90	-17.30	7.96	-17.60	8.01	-17.90
8.07	-18.20	8.12	-18.40	8.18	-18.60	8.23	-18.80
8.28	-18.90	8.34	-19.10	8.39	-19.20	8.44	-19.40
8.49	-19.50	8.54	-19.60	8.59	-19.80	8.64	-19.90
8.69	-20.00	8.74	-20.10	8.79	-20.30	8.84	-20.40
8.89	-20.50	8.94	-20.70	8.99	-20.80	9.03	-20.90
9.08	-21.10	9.13	-21.20	9.18	-21.40	9.22	-21.50
9.27	-21.70	9.32	-21.80	9.36	-21.90	9.41	-22.10
9.45	-22.20	9.50	-22.30	9.54	-22.40	9.59	-22.50
9.63	-22.60	9.67	-22.70	9.72	-22.70	9.76	-22.70
9.81	-22.70	9.85	-22.70	9.89	-22.70	9.94	-22.70
9.98	-22.70	10.03	-22.60	10.07	-22.60	10.12	-22.60
10.16	-22.50	10.20	-22.50	10.25	-22.40	10.29	-22.40
10.34	-22.30	10.38	-22.30	10.43	-22.20	10.47	-22.10
10.52	-22.10	10.56	-22.00	10.61	-22.00	10.65	-21.90
10.70	-21.90	10.75	-21.80	10.79	-21.70	10.84	-21.70
10.88	-21.60	10.93	-21.50	10.98	-21.50	11.02	-21.40
11.07	-21.40	11.12	-21.30	11.16	-21.30	11.21	-21.20
11.26	-21.10	11.31	-21.10	11.35	-21.00	11.40	-21.00
11.45	-20.90	11.50	-20.90	11.54	-20.80	11.59	-20.80
11.64	-20.70	11.69	-20.70	11.74	-20.60	11.79	-20.60

TABLE 6. SPIN FOR Mk66 Mod 1 ROCKET NUMBER B 2
YAWSONDE NUMBER 1729 (CONT).

TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)	TIME (SEC)	SPIN (RPS)
11.84	-20.50	11.88	-20.50	11.93	-20.50	11.98	-20.40
12.03	-20.40	12.08	-20.30	12.13	-20.30	12.18	-20.20
12.23	-20.20	12.28	-20.20	12.33	-20.10	12.38	-20.10
12.43	-20.00	12.48	-20.00	12.53	-20.00	12.58	-19.90
12.63	-19.90	12.68	-19.90	12.73	-19.80	12.78	-19.80
12.83	-19.80	12.88	-19.70	12.93	-19.70	12.98	-19.70
13.03	-19.60	13.08	-19.60	13.14	-19.60	13.19	-19.50
13.24	-19.50	13.29	-19.50	13.34	-19.40	13.39	-19.40
13.44	-19.40	13.50	-19.30	13.55	-19.30	13.60	-19.30
13.65	-19.20	13.70	-19.20	13.75	-19.20	13.81	-19.20
13.86	-19.10	13.91	-19.10	13.96	-19.10	14.02	-19.00
14.07	-19.00	14.12	-19.00	14.17	-19.00	14.23	-18.90
14.28	-18.90	14.33	-18.90	14.39	-18.80	14.44	-18.80
14.49	-18.80	14.55	-18.70	14.60	-18.70	14.65	-18.70
14.71	-18.70	14.76	-18.60	14.81	-18.60	14.87	-18.60
14.92	-18.60	14.98	-18.50	15.03	-18.50	15.08	-18.50
15.14	-18.50	15.19	-18.40	15.25	-18.40	15.30	-18.40
15.36	-18.30	15.41	-18.30	15.47	-18.30	15.52	-18.20
15.58	-18.20	15.63	-18.20	15.68	-18 20	15.74	-18.10
15.79	-18.10	15.85	-18.10	15.91	-18.00	15.96	-18.00
16.02	-18.00	16.07	-17.90	16.13	-17.90	16.18	-17.90
16.24	-17.80	16.30	-17.80	16.35	-17.80	16.41	-17.80
16.47	-17.70	16.52	-17.70	16.58	-17.70	16.63	-17.70
16.69	-17.60	16.75	-17.60	16.81	-17.60	16.86	-17.50
16.92	-17.50	16.98	-17.50	17.03	-17.50	17.09	-17.40
17.15	-17.40	17.21	-17.40	17.26	-17.30	17.32	-17.30
17.38	-17.30	17.44	-17.30	17.50	-17.30	17.55	-17.20
17.61	-17.20	17.67	-17.20	17.73	-17.10	17.79	-17.10
17.85	-17.10	17.90	-17.10	17.96	-17.10	18.02	-17.00
18.08	-17.00	18.14	-17.00	18.20	-16.90	18.26	-16.90
18.32	-16.90	18.38	-16.90	18.43	-16.80	18.49	-16.80
18.55	-16.80	18.61	-16.80	18.67	-16.70	18.73	-16.70
18.79	-16.70	18.85	-16.70	18.91	-16.60	18.97	-16.60
19.03	-16.60	19.09	-16.60	19.15	-16.50	19.21	-16.50
19.28	-16.50	19.34	-16.50	19.40	-16.40	19.46	-16.40

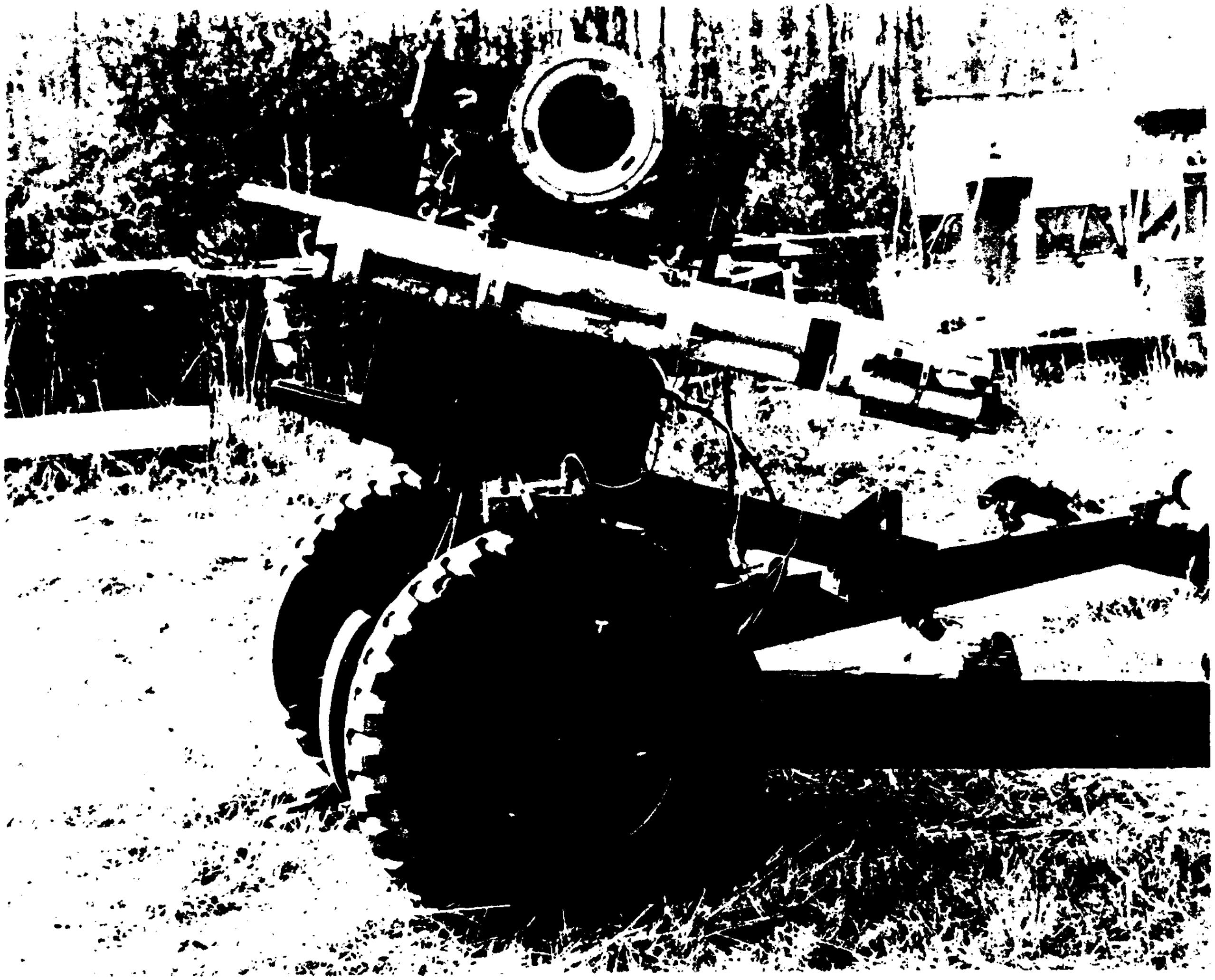

Figure 1. Photograph of the 2.75-Inch Rocket Launcher and Mount

Figure 2. Photograph of the 2.75-Inch Rocket in the Launcher

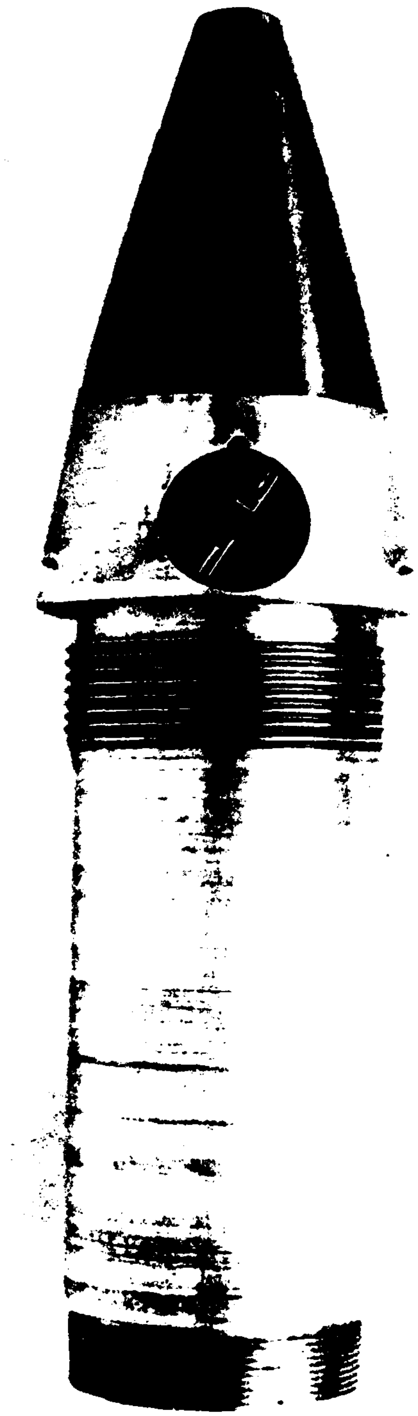

Figure 3. Modified Yawsonde Assembly for the 2.75-Inch Rocket Test

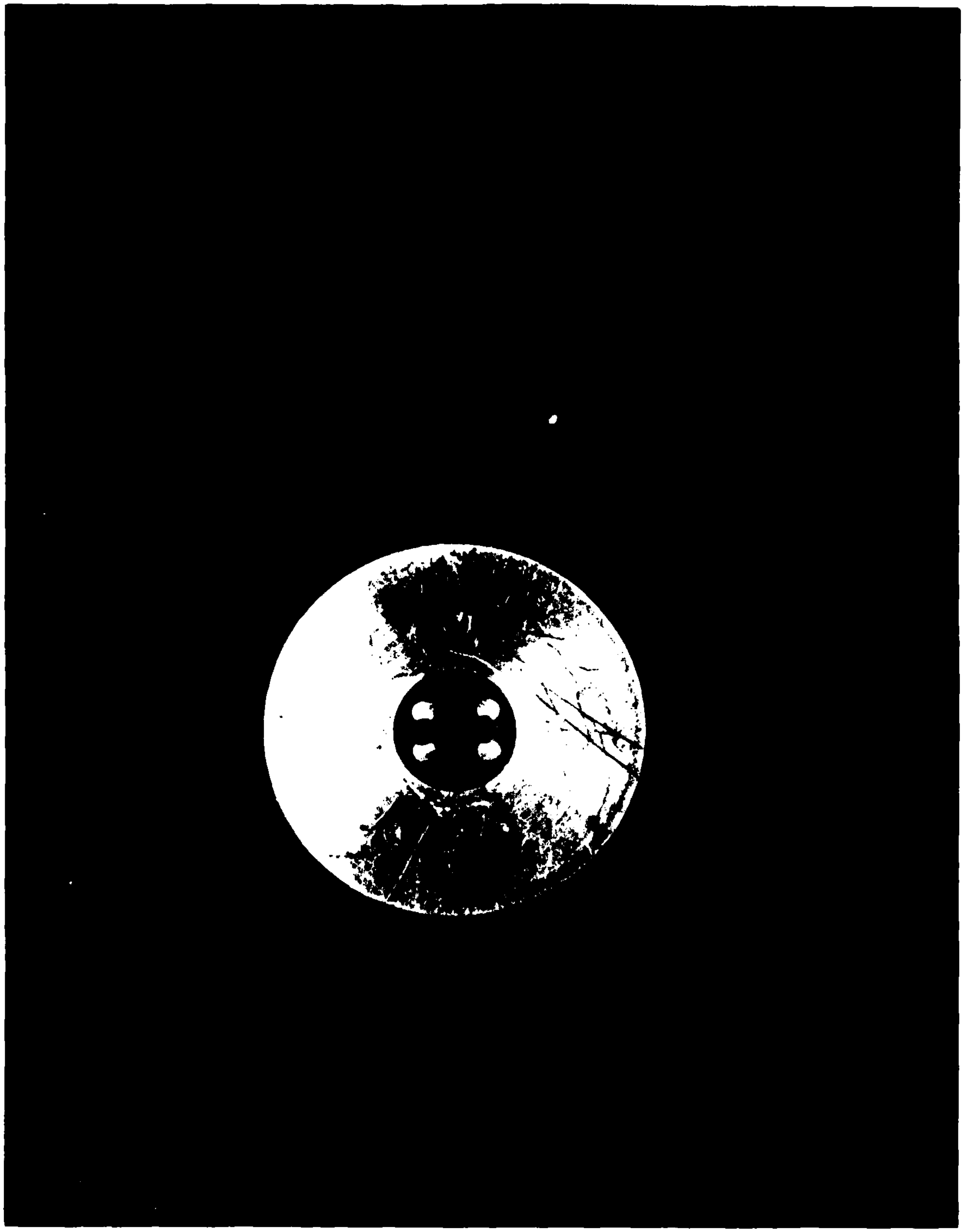

Figure 4. Modified Base Cap Showing Turn-On Switch

Figure 5. Yawsonde Instrumented Mk66 Mod 1 Rocket

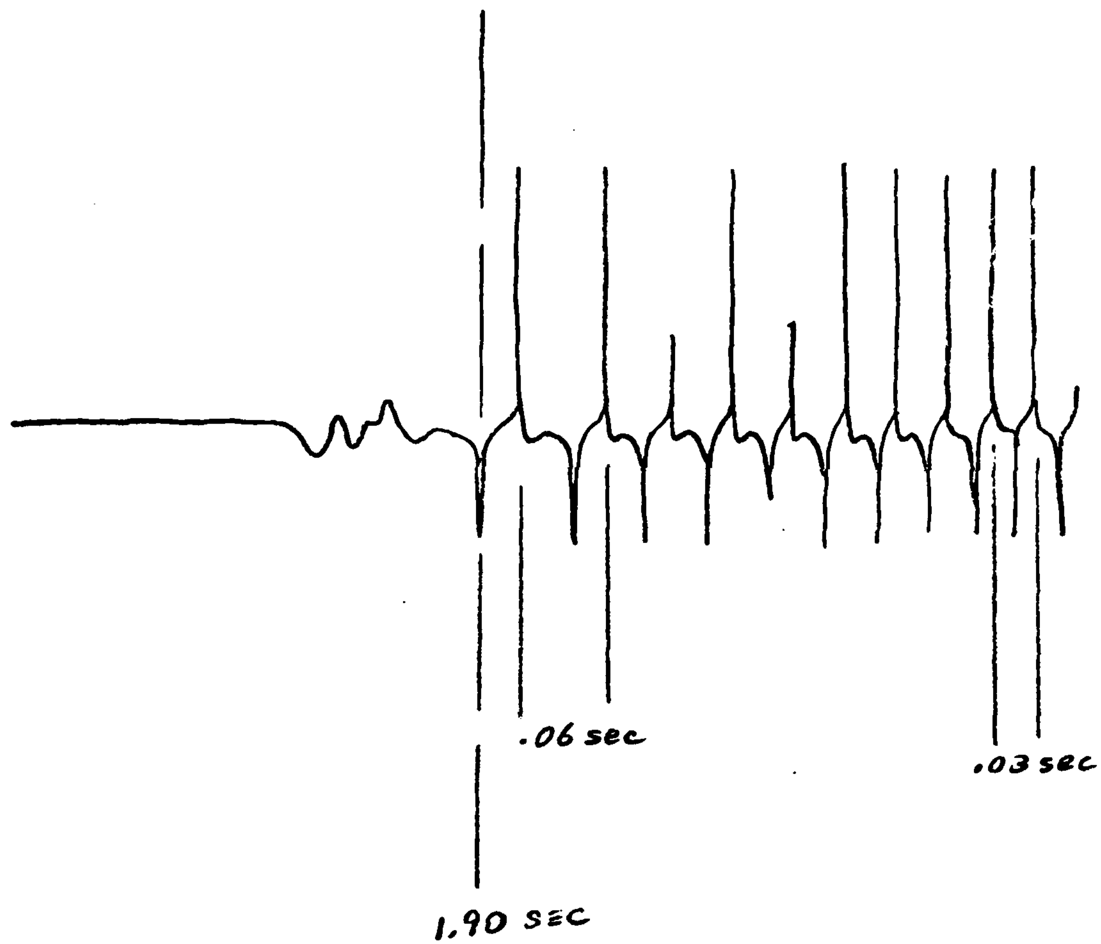

Figure 6A. Oscillograph Record from Rocket B1 (Yawsonde 1731) at the Beginning of Flight

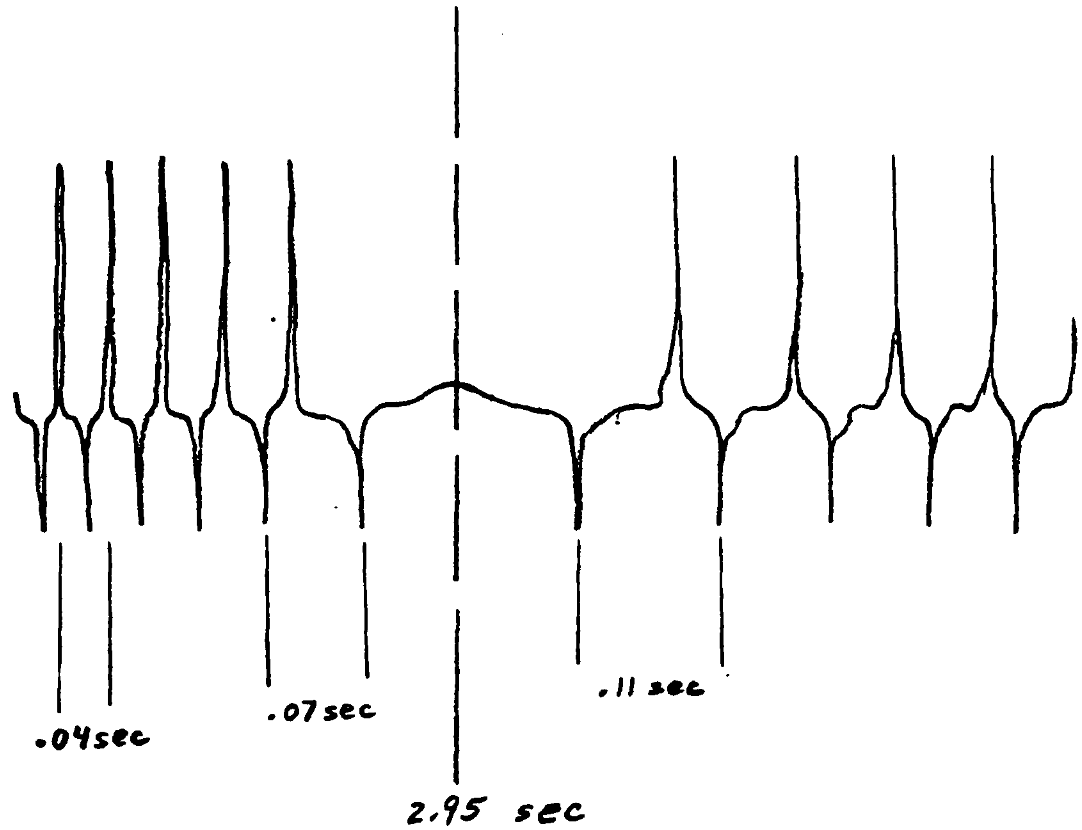

Figure 6B. Oscillograph Record from Rocket B1 (Yawsonde 1731) at the Spin Cross-Over

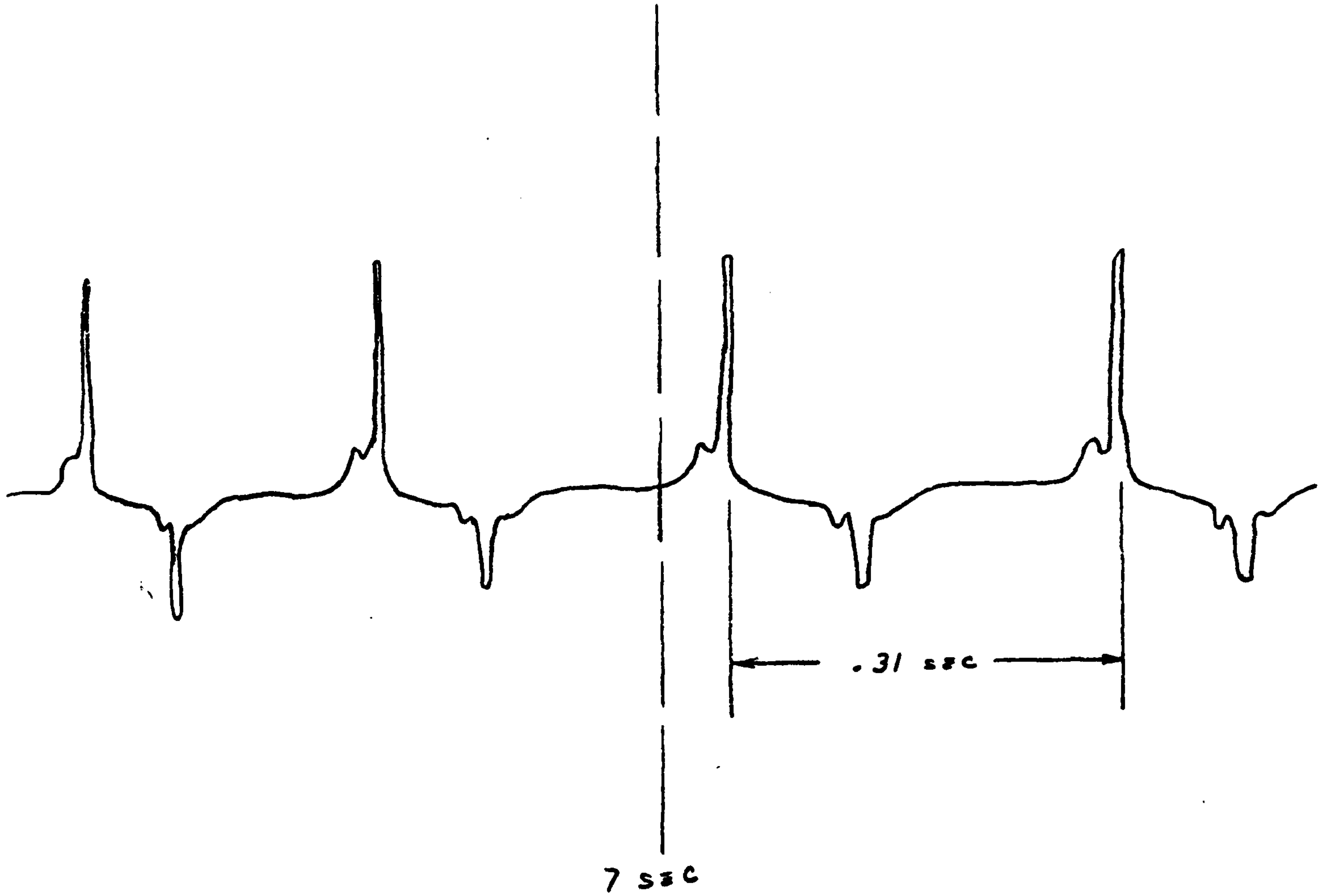

Figure 6C. Oscillograph Record from Rocket B1 (Yawsonde 1731) at the Negative Spin Plateau

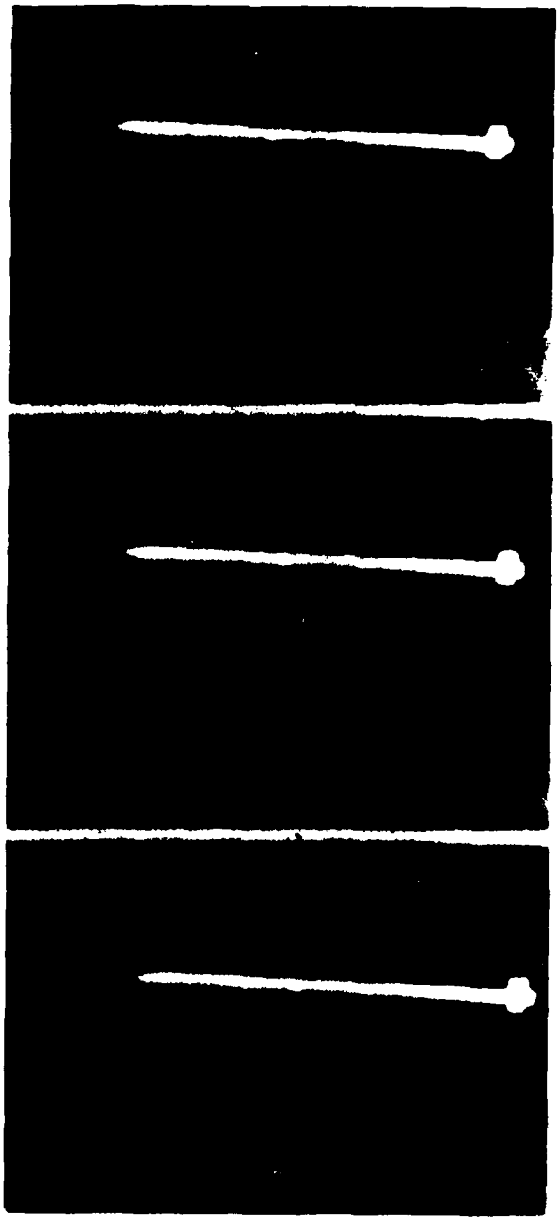

Figure 7. Framing Camera Record of Rocket Number B1 in Flight

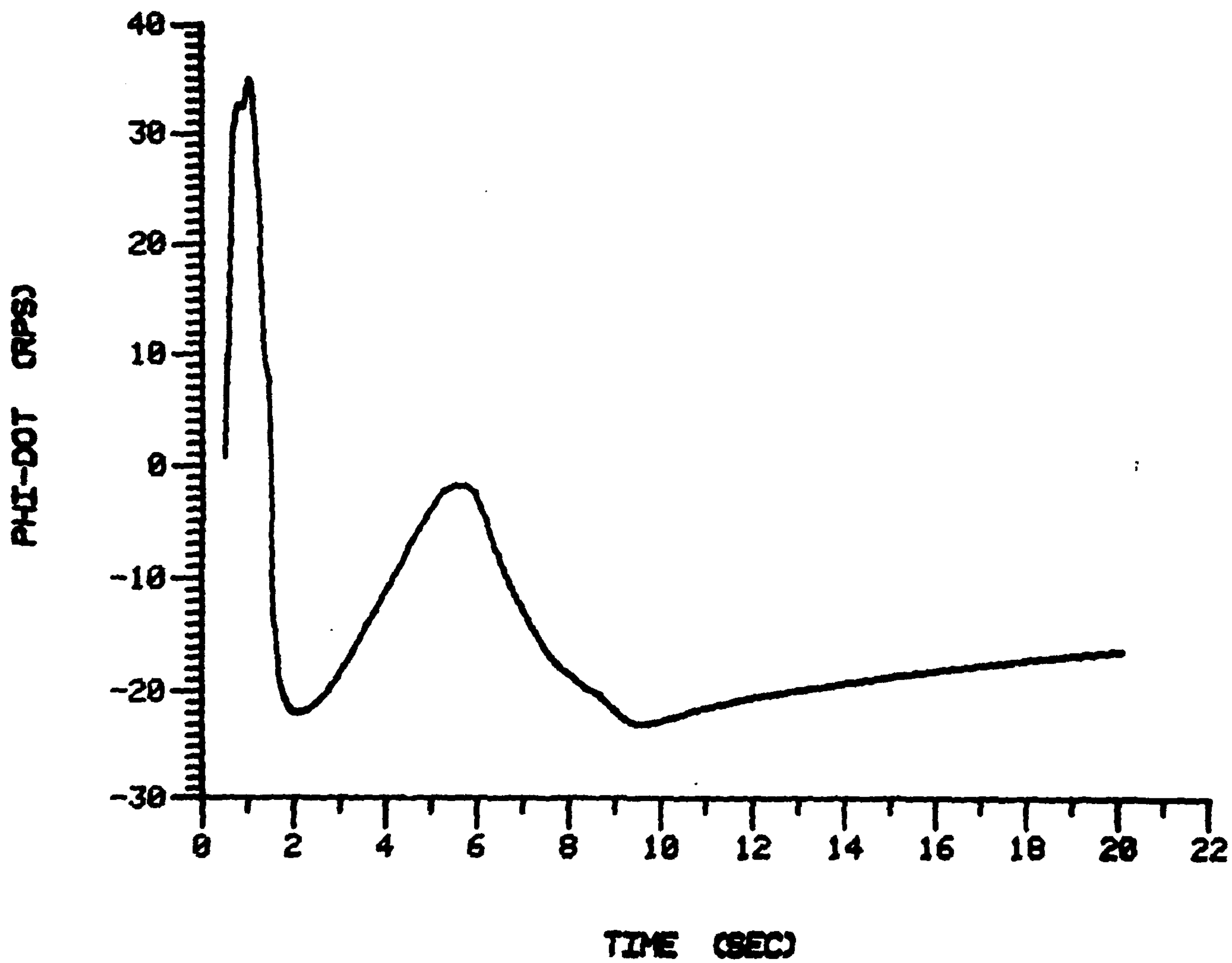

Figure 8. Spin History from Rocket A2.

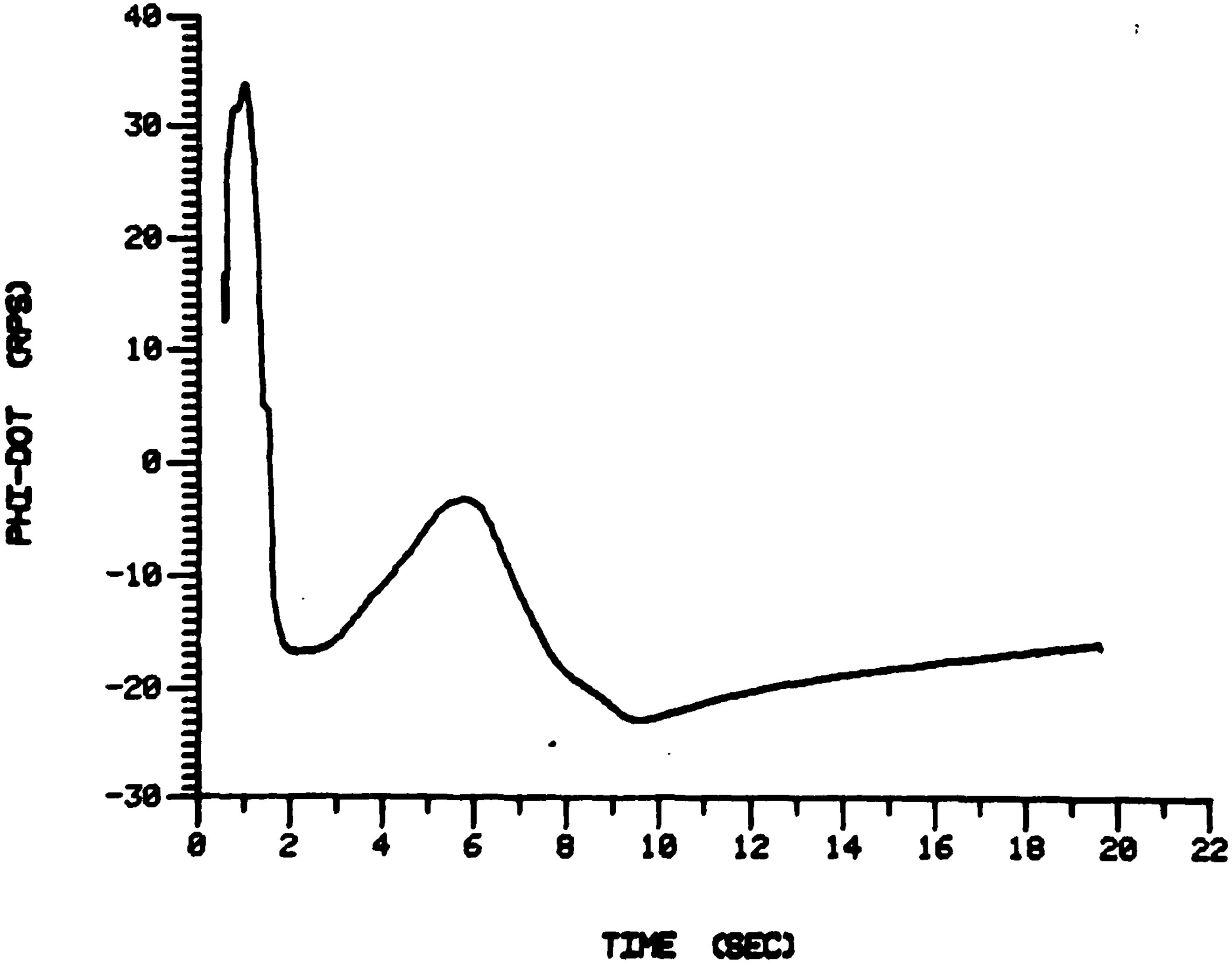

Figure 9. Spin History from Rocket B1.

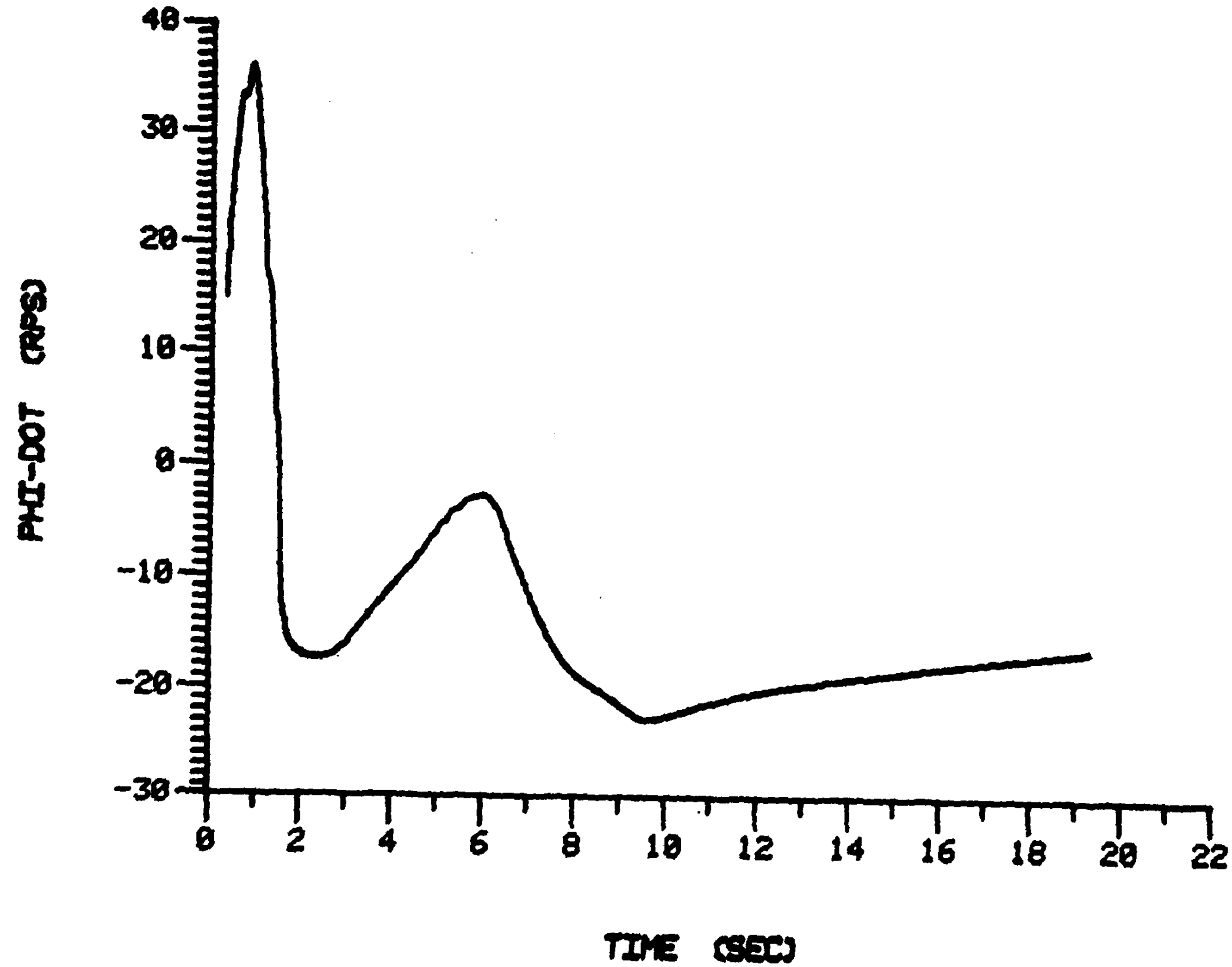

Figure 10. Spin History from Rocket B2.

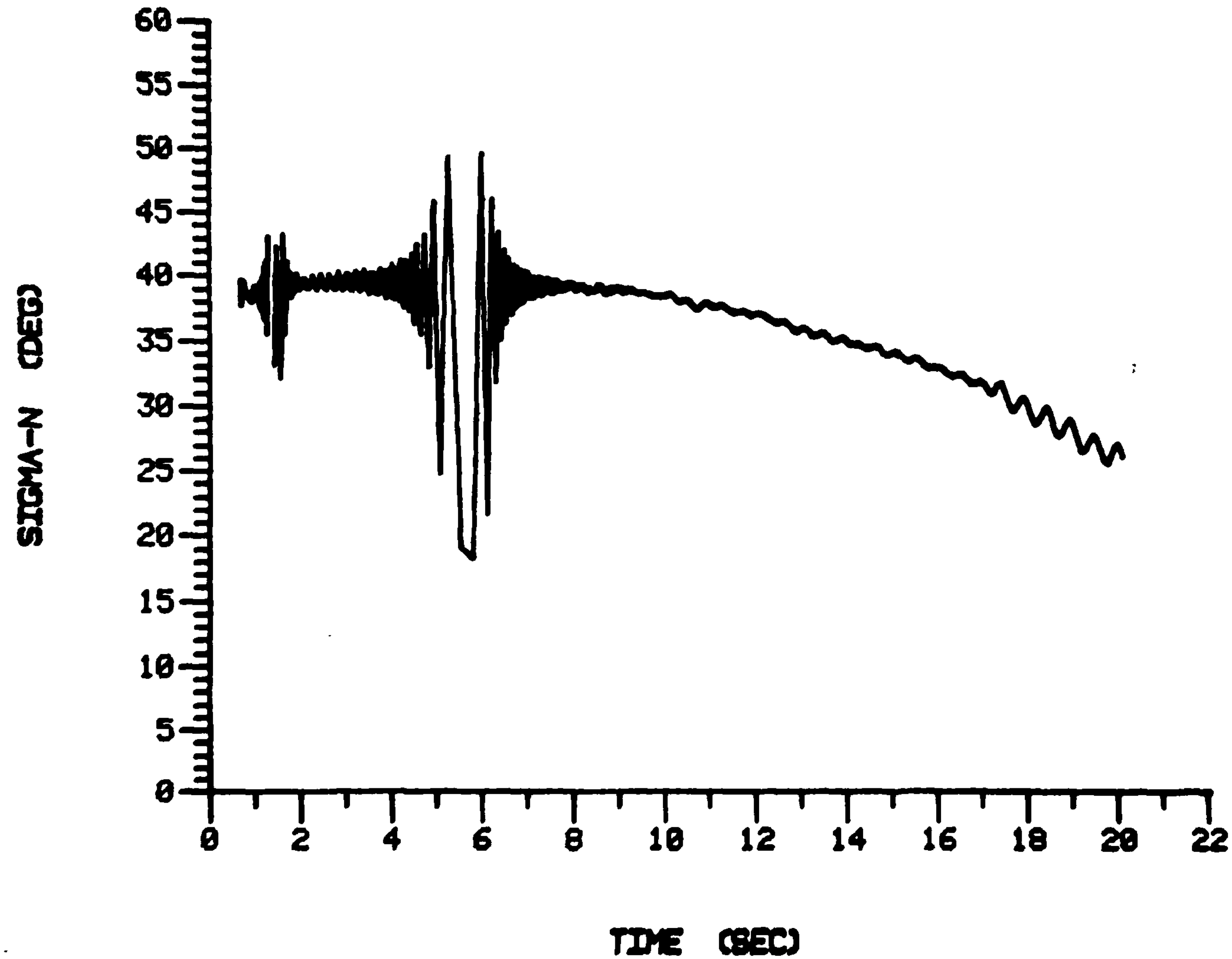

Figure 11. Solar Aspect Angle History from Rocket A2.

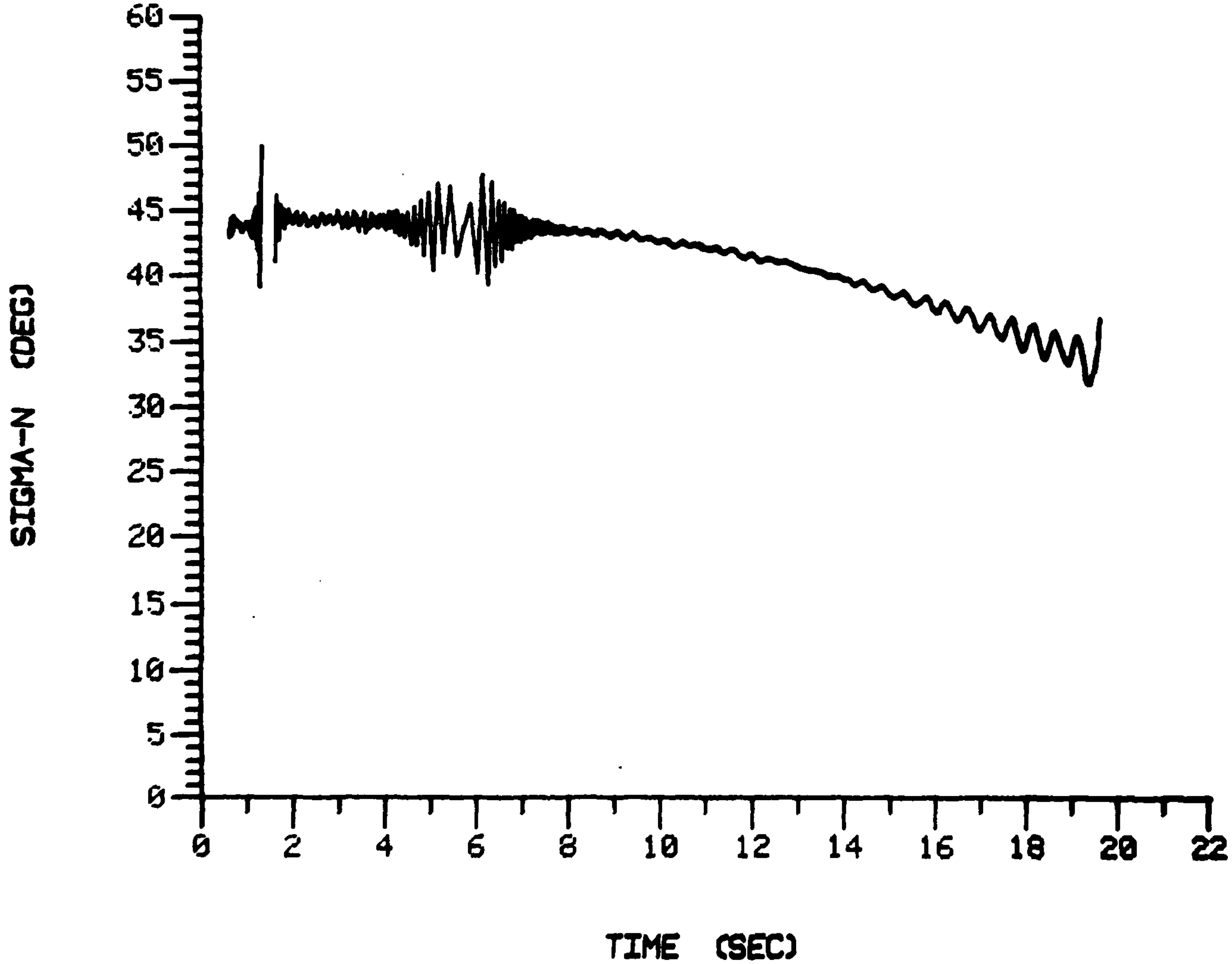

Figure 12. Solar Aspect Angle History from Rocket B1.

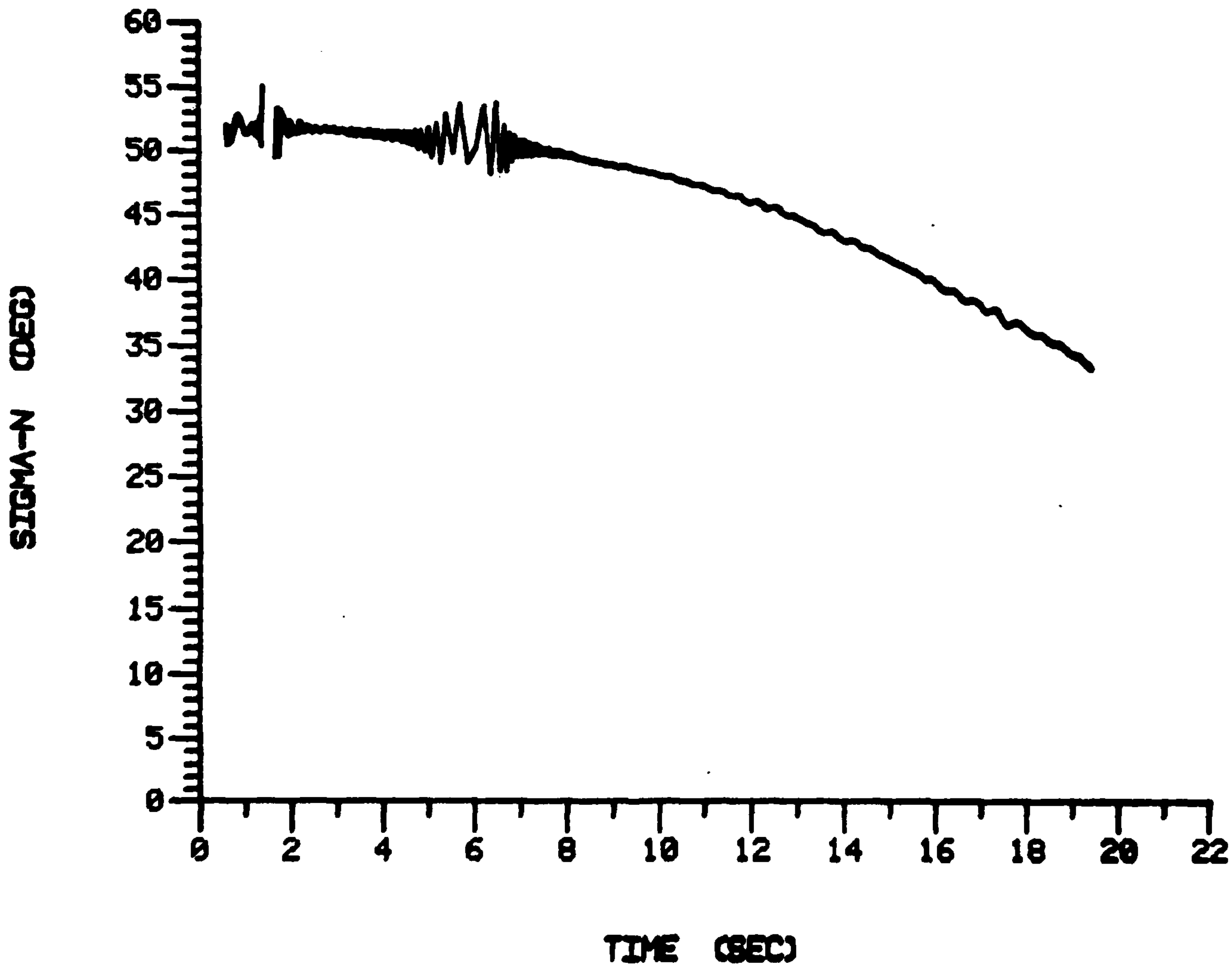

Figure 13. Solar Aspect Angle History from Rocket B2.

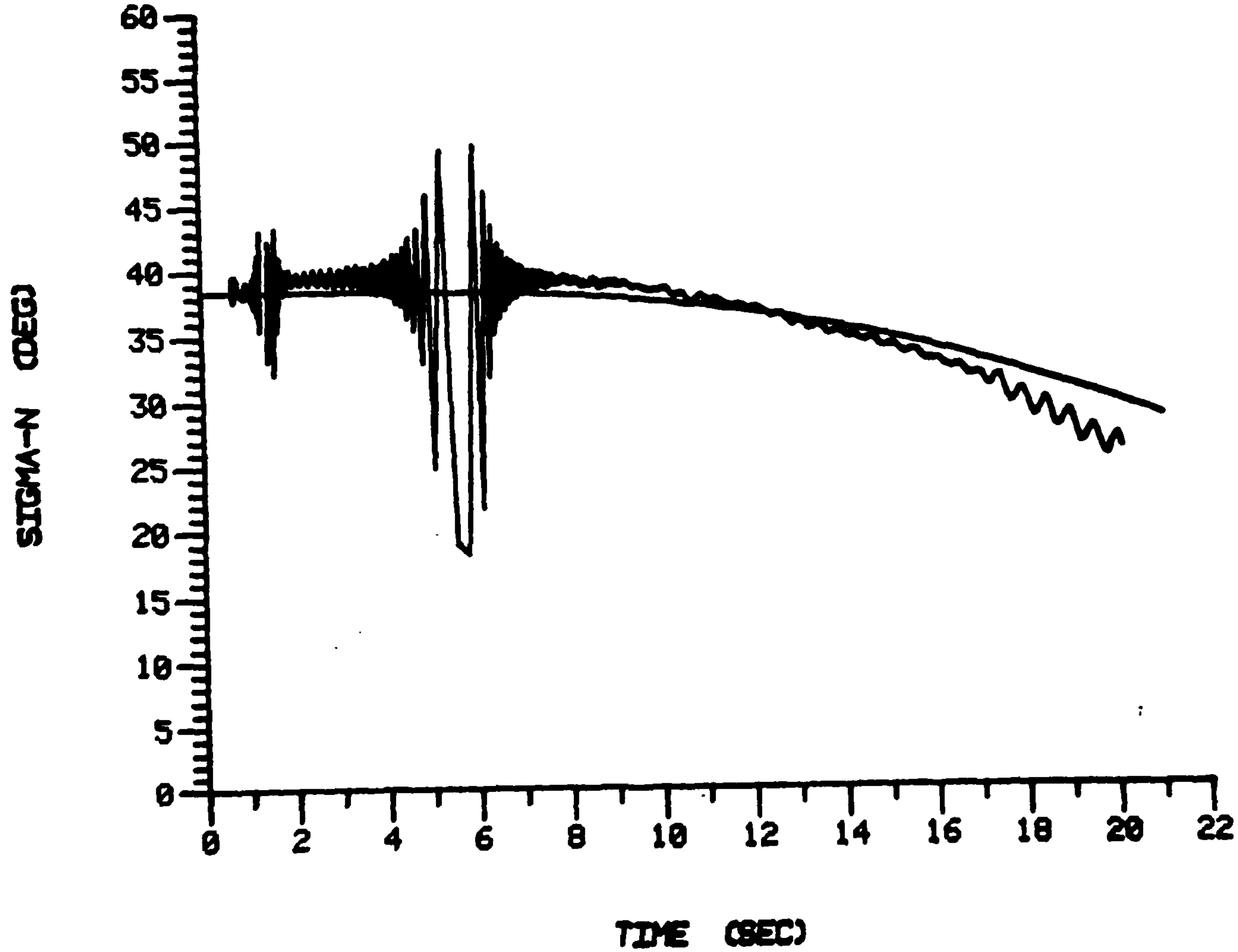

Figure 14. Solar Aspect Angle vs. Zero-Yaw Aspect Angle for Rocket A2. The smooth curve is the computed Zero-Yaw Aspect Angle.

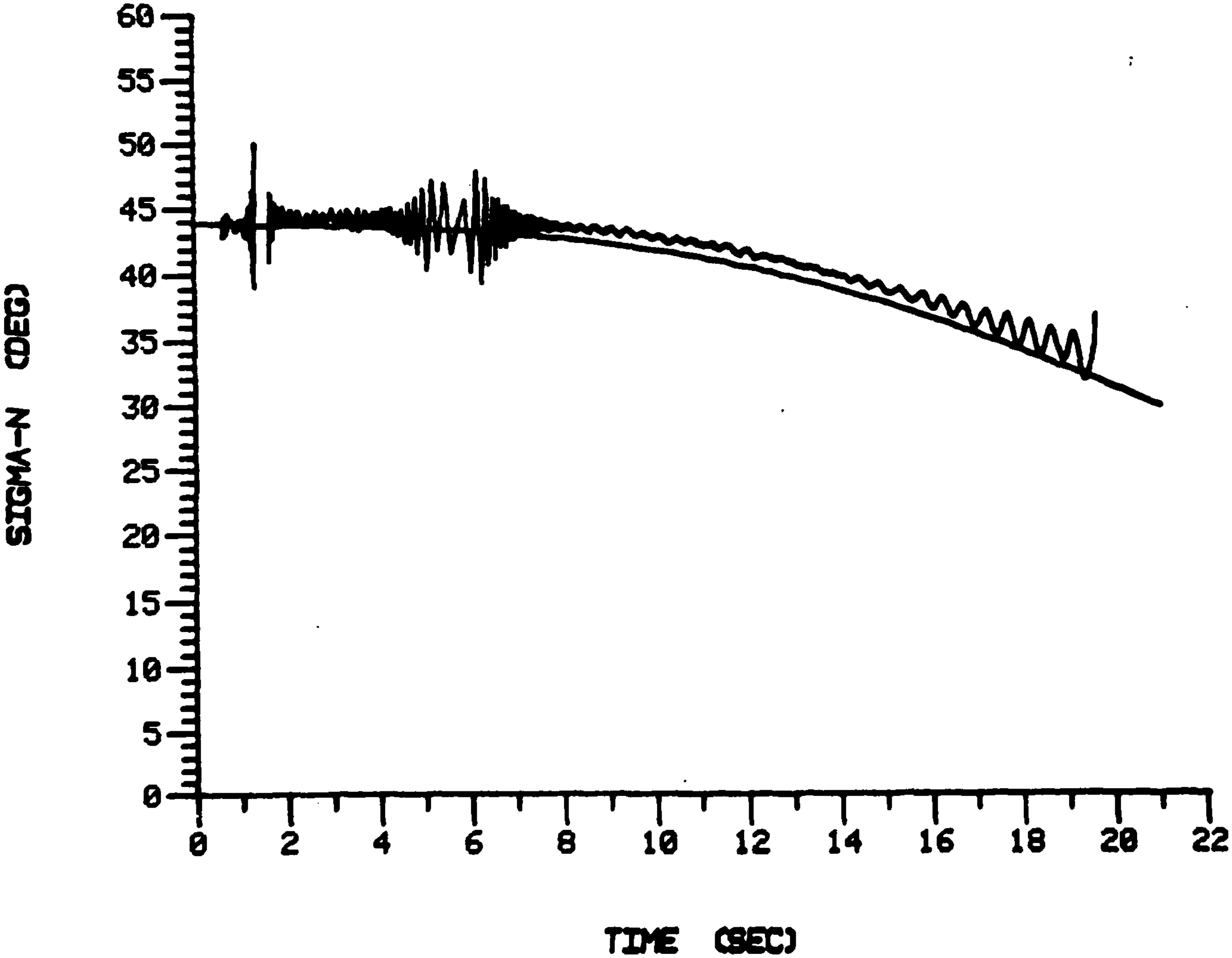

Figure 15. Solar Aspect Angle vs. Zero-Yaw Aspect for Rocket B1. The smooth curve is the computed Zero-Yaw Aspect Angle.

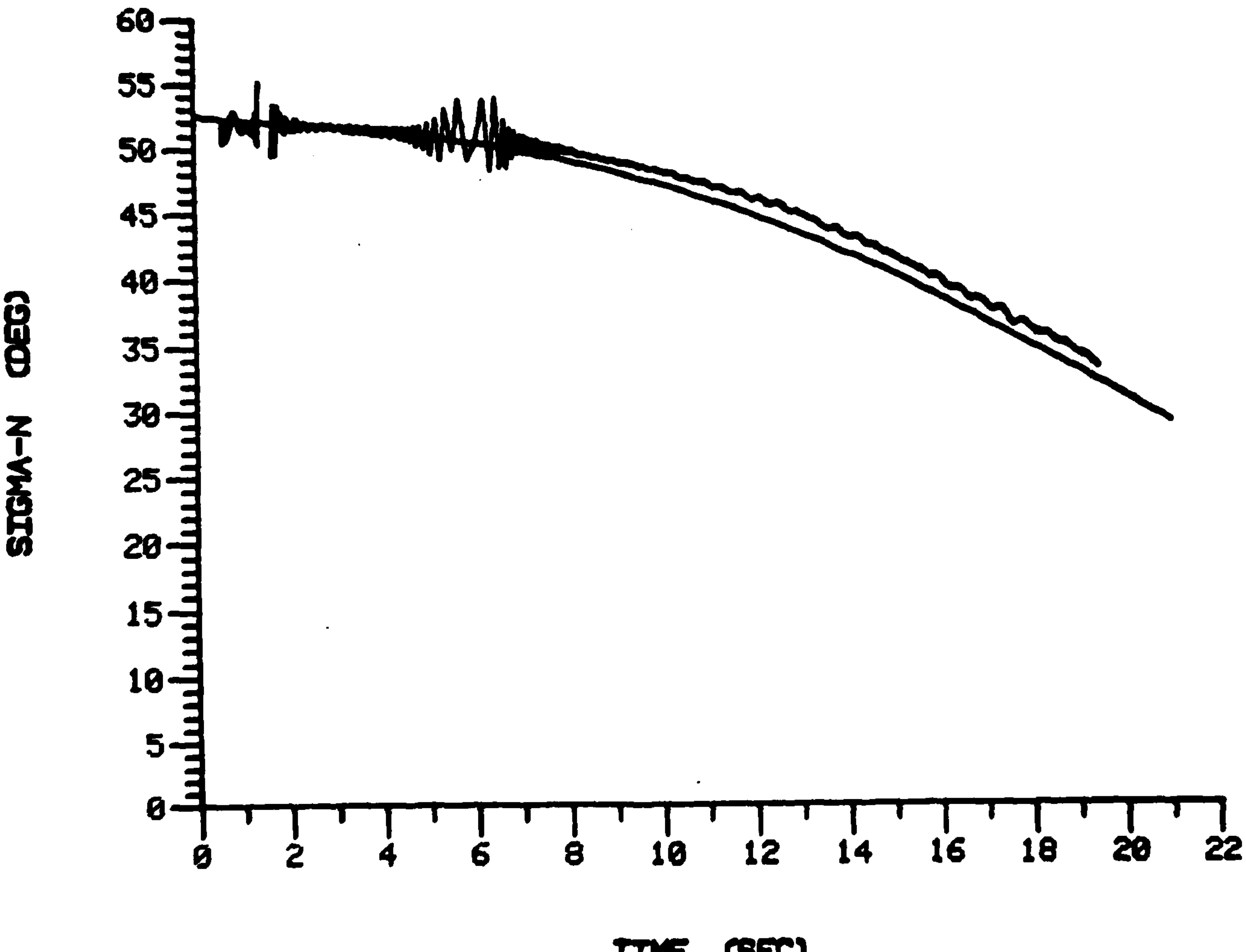

Figure 16. Solar Aspect Angle vs. Zero-Yaw Aspect for Rocket B2. The smooth curve is the computed Zero-Yaw Aspect Angle.

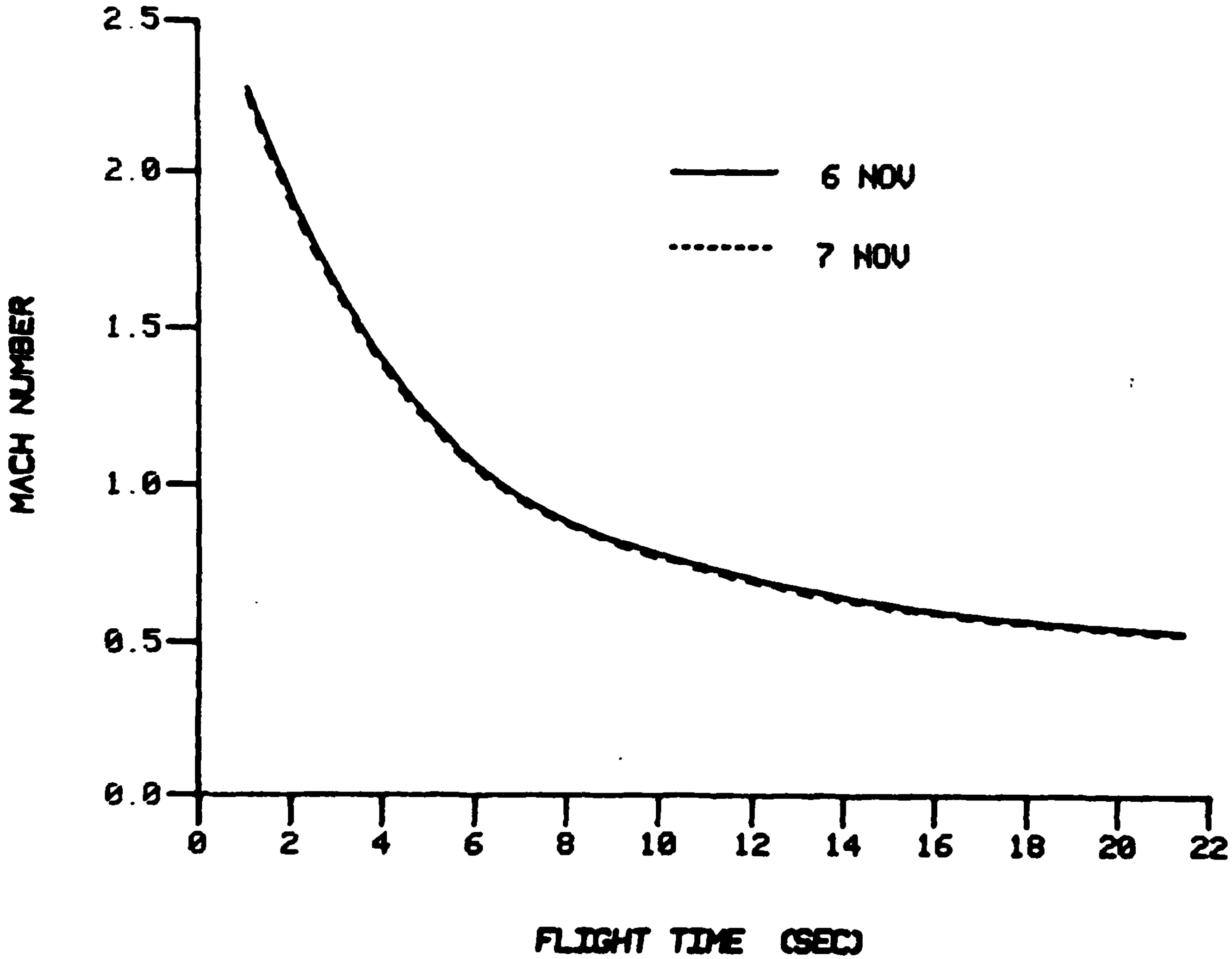

Figure 17. Comparison of Mach Number Histories for Two Firing Dates.

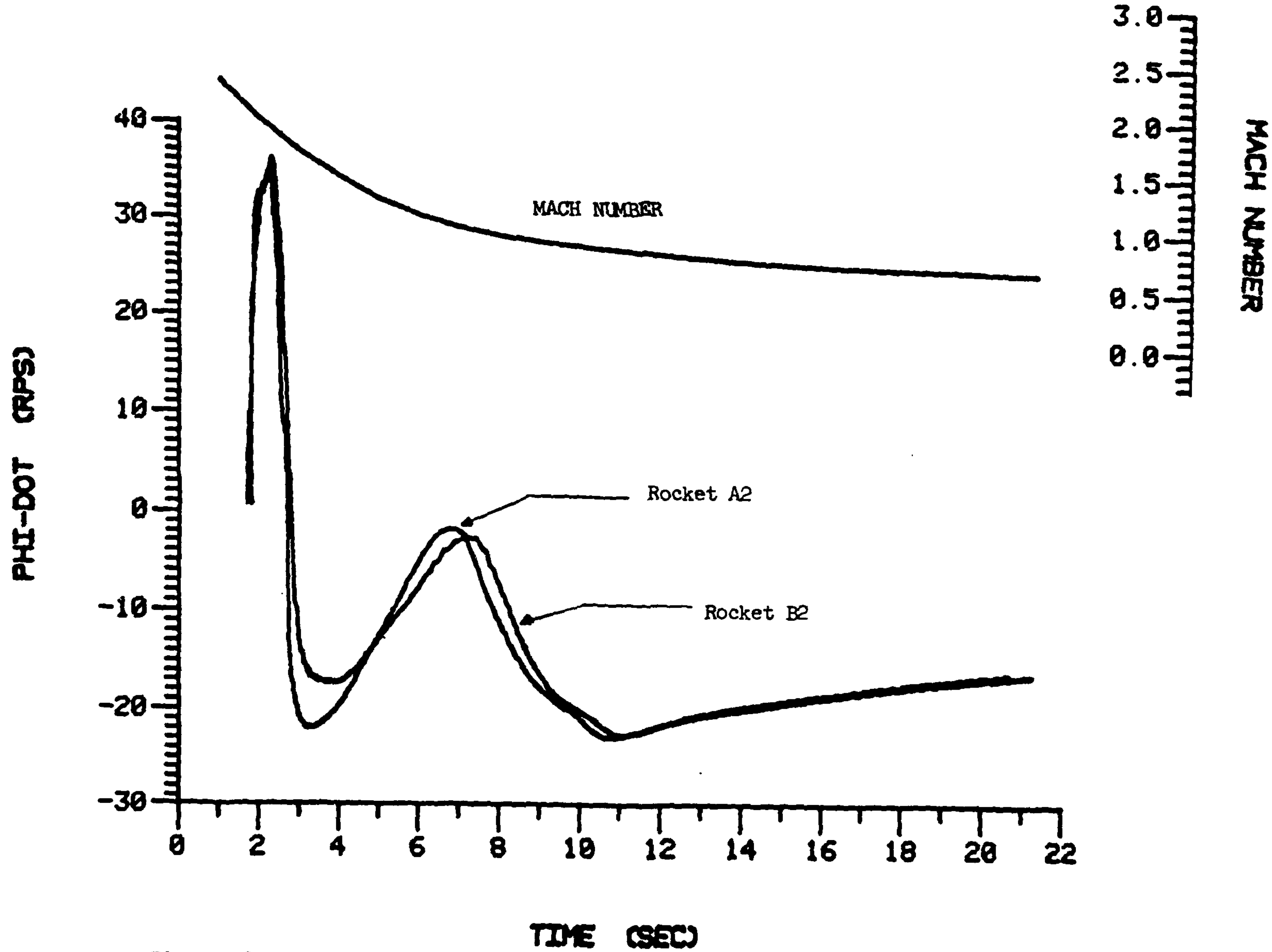

Figure 18. Comparison of Spin Data from Rockets A2 and B2.

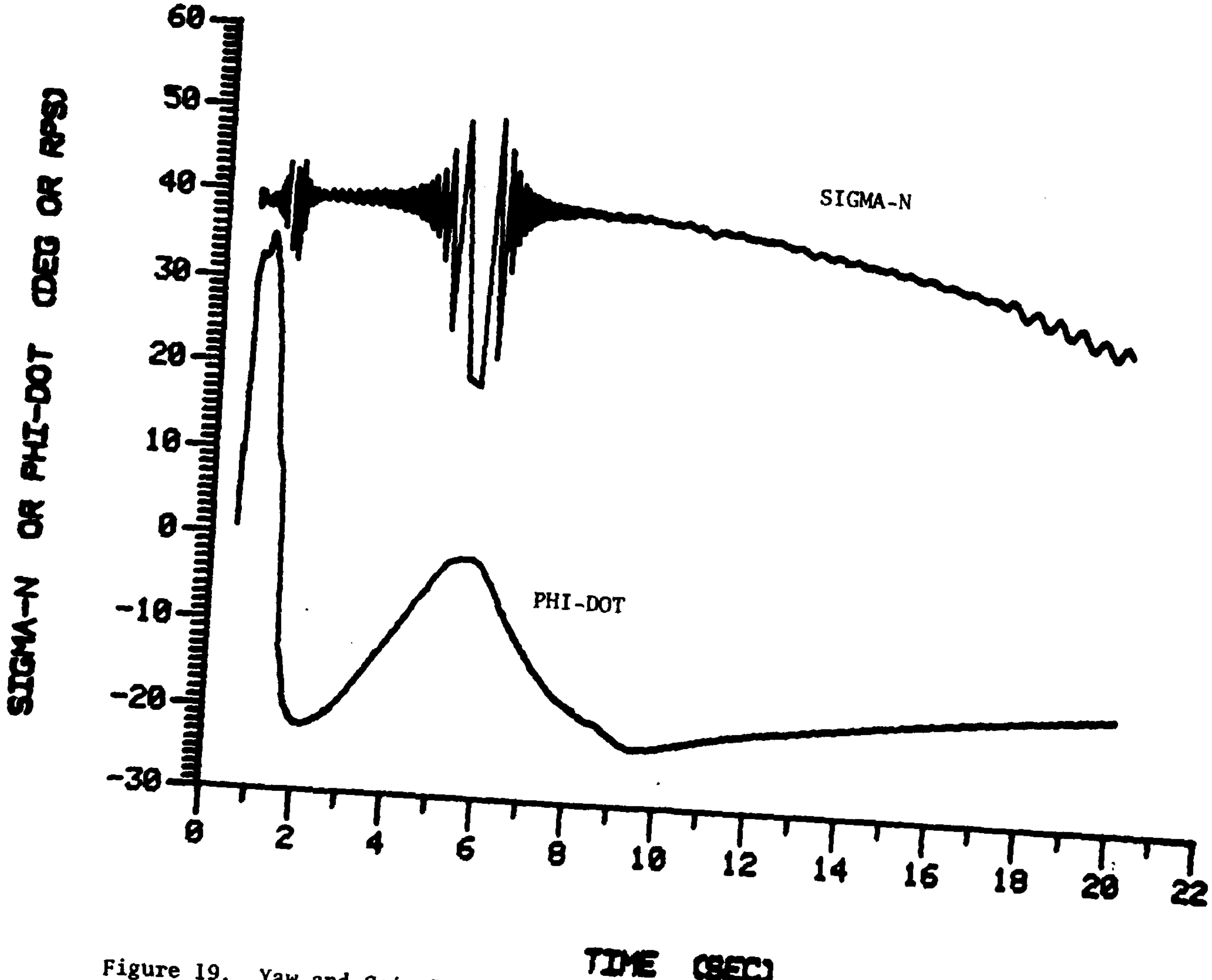

Figure 19. Yaw and Spin Behavior of Rocket Number A2.

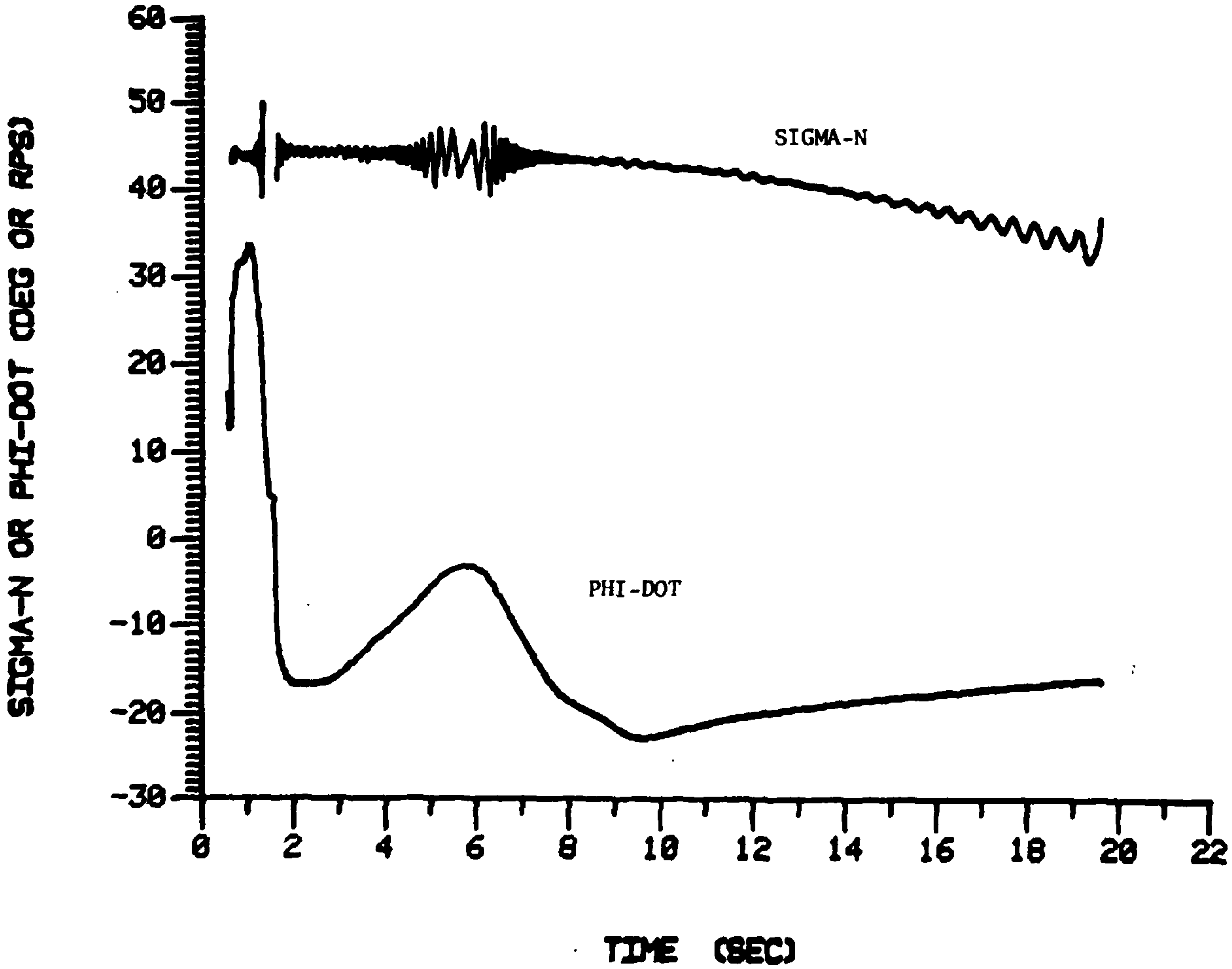

Figure 20. Yaw and Spin Behavior of Rocket Number B1.

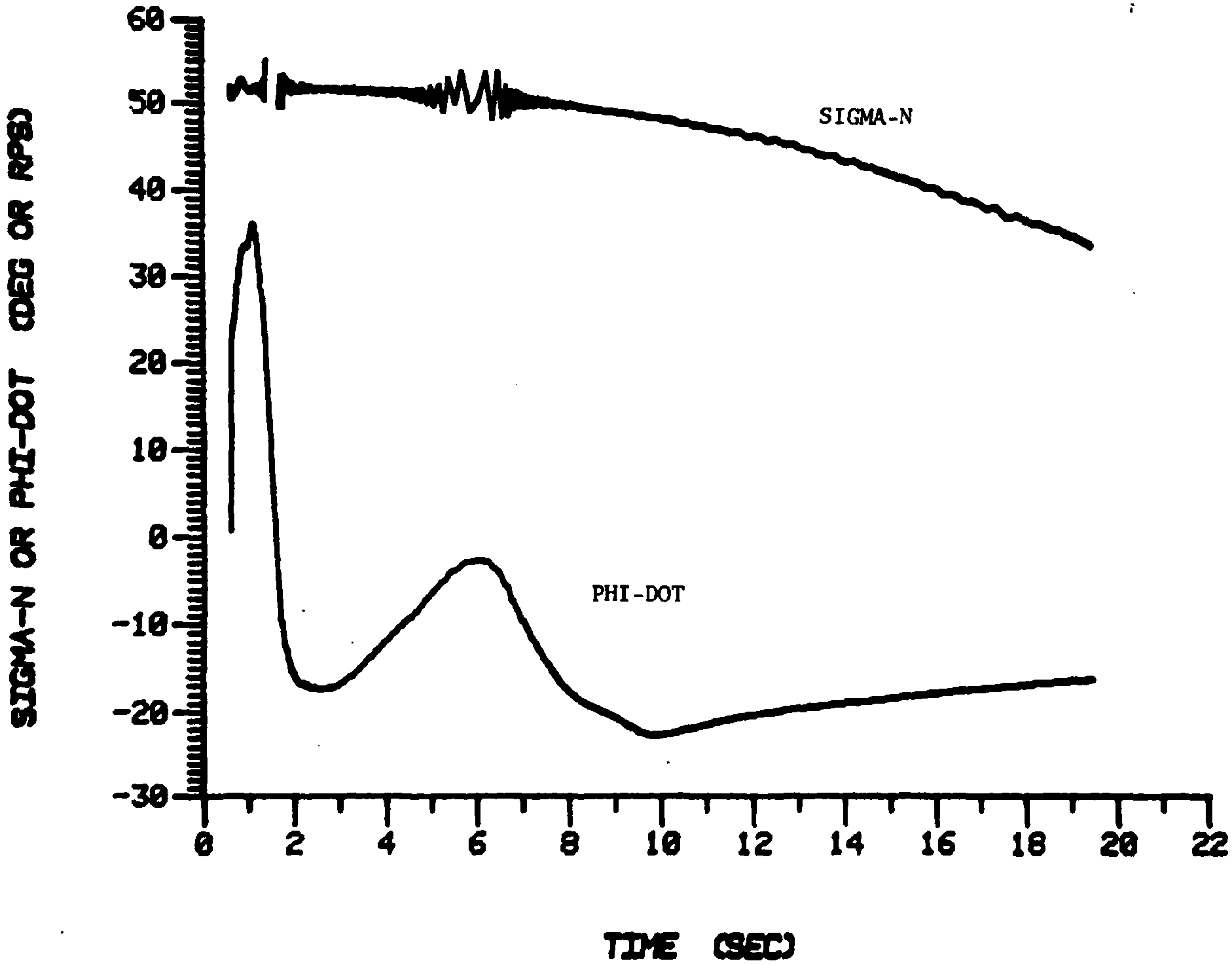

Figure 21. Yaw and Spin Behavior of Rocket Number B2.

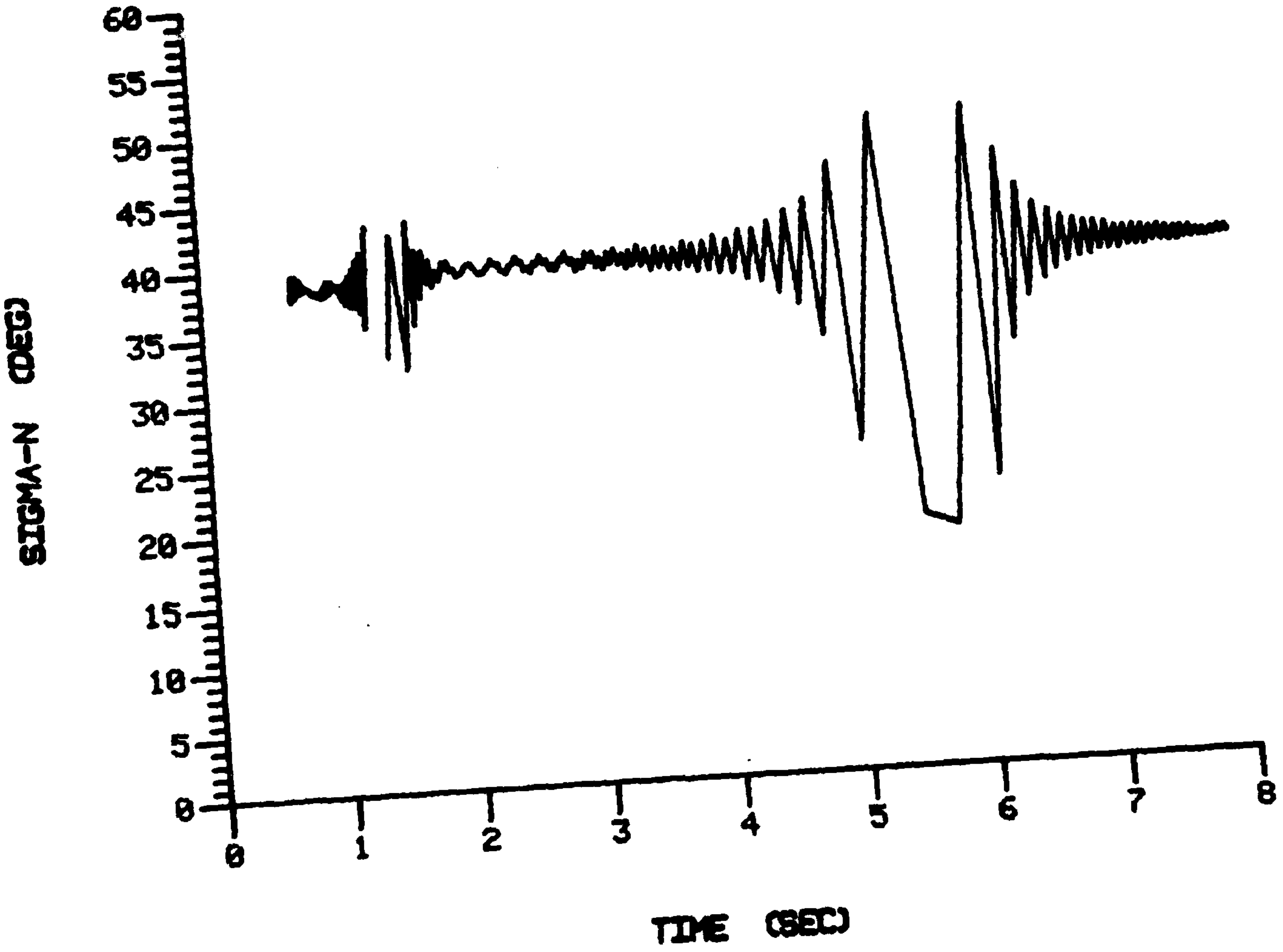

Figure 22. First Eight Seconds of Flight - Rocket A2.

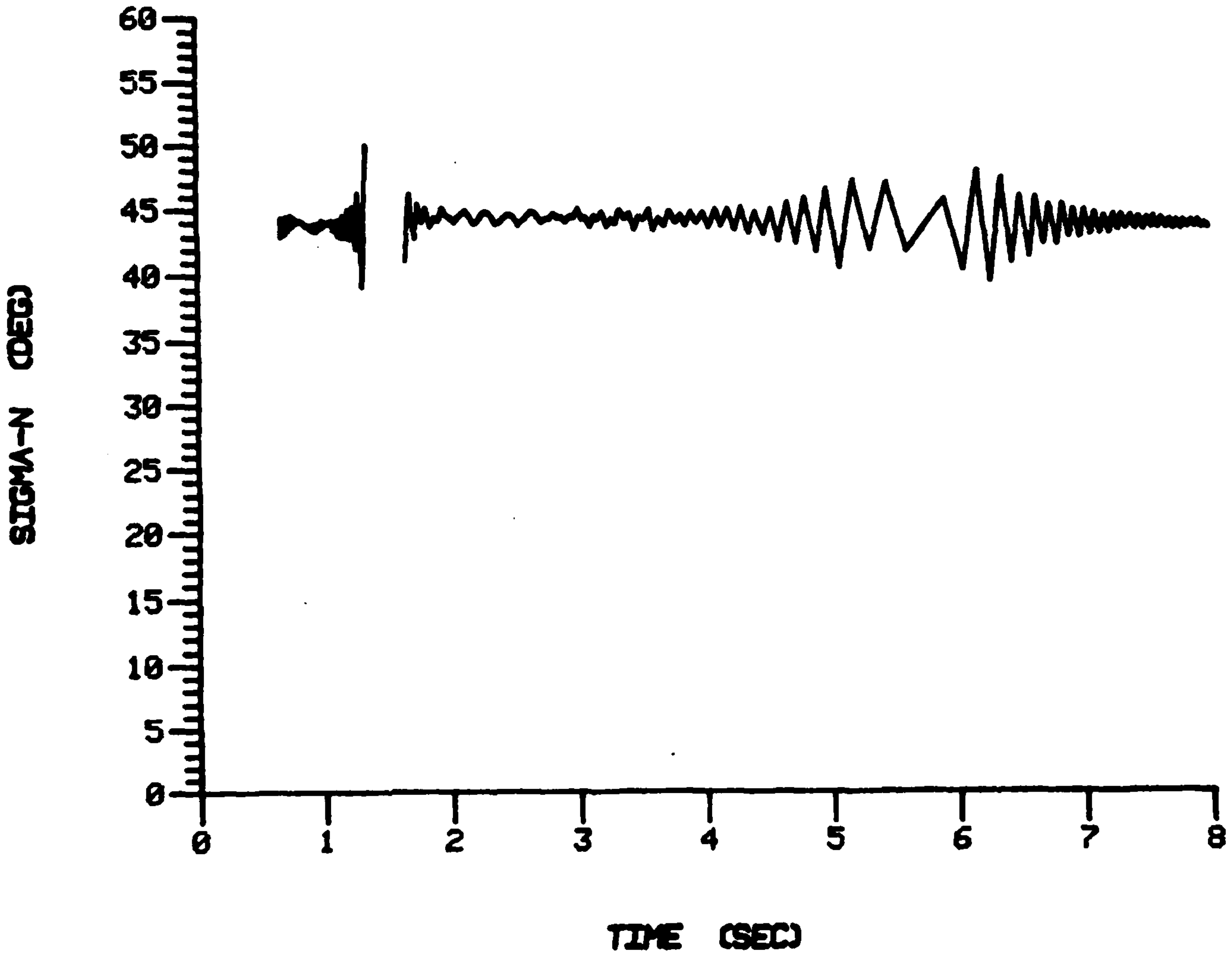

Figure 23. First Eight Seconds of Flight - Rocket B1.

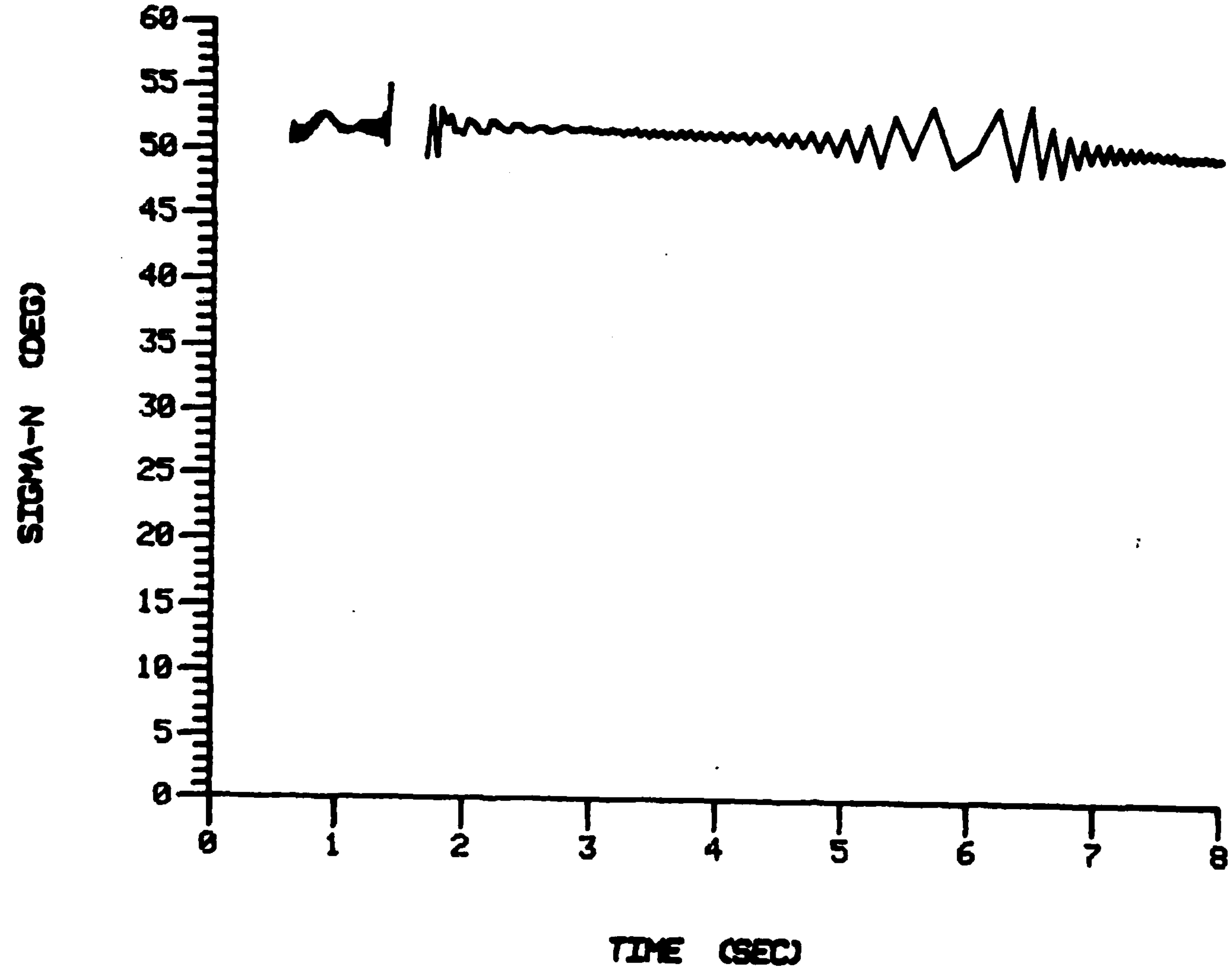

Figure 24. First Eight Seconds of Flight - Rocket B2.

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